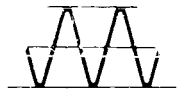
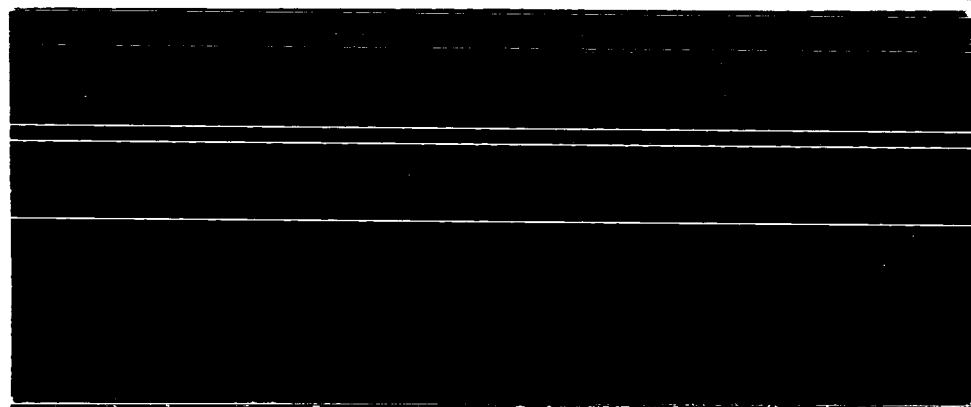


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N O R T H R O N I C S



A DIVISION OF
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(NORT 60-46)

TECHNICAL DESCRIPTION AND
OPERATING INSTRUCTIONS [FOR]
NASA FLOW-DIRECTION
AND PITOT-PRESSURE SENSOR

(NASA Contracts NAI-3200 and NAS4-82)

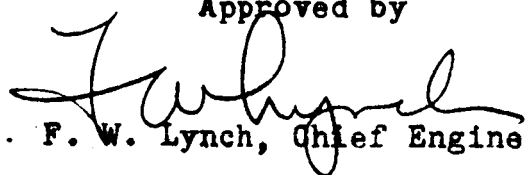
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Prepared by

Flight Safety and Controls Development Unit
Electronic Systems and Equipment Department

Approved by


F. W. Lynch, Chief Engineer

080276

N O R T R O N I C S



A DIVISION OF
NORTHROP CORPORATION

This report contains a technical description and operating instructions for the Flow-Direction and Pitot-Pressure Sensor, Part No. 5212138, produced for the National Aeronautics and Space Administration by Nortronics Division of Northrop Corporation under N.A.S.A. Contracts NAI-3200 and NAS4-82.

TABLE OF CONTENTS

<u>Section</u>	<u>Page</u>
I SCOPE	1
II EQUIPMENT	1
III APPLICABLE DOCUMENTS	1
IV SENSOR TECHNICAL DESCRIPTION	2
1. General Features	2
2. Principle of Operation	6
3. Sensor Physical Description	7
3.1 Servo System	7
3.2 Electrical System	15
3.3 Hydraulic System	15
3.4 Cooling System	19
3.5 In-flight Test System	24
4. Sensor Operating Characteristics	26
4.1 Range of Sphere Angular Travels	26
4.2 Electrical Zero and Polarity of The α and β Synchro Transmitters	26
4.3 Dynamic Pressure Range of Servo Gain Compensation	27
4.4 Static Accuracy of Flow Angle Measurement	27
4.5 Frequency Response Characteristics	29
4.6 Sensor α and β Servo Velocity Characteristics	35



<u>Section</u>	<u>Page</u>
4.7 Threshold of The α or β Servo System	37
4.8 Backlash of The α or β Servo Systems	38
4.9 In-flight Test System	38
4.10 Gain Changing Servo Characteristics	43
4.11 Sensor Thermal Characteristics	47
5. Special Assembly Instructions	49
5.1 Polarity and Null Alignment of The β Synchro Transmitter	50
5.2 Polarity and Null Alignment of The α Synchro Transmitter	52
5.3 Assembly Adjustments of The Gain Changing Servo Assembly	53
5.4 Electronic Circuit Balance Adjustments	57
6. Sensor Parts List	60
6.1 Nortronics Fabricated Parts	60
6.2 Sensor Commercial Parts	65

LIST OF ILLUSTRATIONS

<u>Figure</u>		<u>Page</u>
1	External Configuration - NASA Flow-Direction Sensor	5
2	α or β Servo Mechanization Schematic	8
3	α or β Servo Mechanization Diagram	9
4	α or β Servo Block Diagram	11
5	Controller Assembly - Electronic	12
6	Circuit Schematic - α or β	13
7	Circuit Schematic - q Compensator And Failure Warning	14
8	Schematic Diagram - Sphere Port Pressure Lines	16
9	Wiring Schematic - Flow-Direction Sensor	17
10	Schematic Diagram - Hydraulic System	18
10A	Actuation Assembly - NASA Sensor	20
11	Cooling System - Mechanization Diagram	21
11A	Circuit Diagram - Sensor Temperature Control System	22
12	Schematic Diagram - Sensor In-flight Test System	25
12A	Variation of Pressure Distribution Along Spherical Surface	28
13	Sensor Static Accuracy	30
14	Closed Outer Loop Frequency Response	31
15	α or β Positional Servo Frequency Response Characteristics	34
16	Sphere Recovery Characteristics After Release of Test Command	42



<u>Figure</u>		<u>Page</u>
17	Mechanization Diagram - Gain Changing Servo	44
18	β Synchro Installation	49
19	Synchro Polarity And Null Alignment	50
20	α Synchro Installation	52
21	q Servo Slip Clutch Adjustment	54
22	q Servo Potentiometer Alignment	55
23	q Servo Potentiometer Location	56



I SCOPE

This report contains technical information pertaining to the operation of the N.A.S.A. Flow-Direction Sensor. Included are: a technical description of the Sensor, special assembly instructions, operating characteristics, wiring diagrams, and parts list.

II EQUIPMENT

Applicable equipment includes the Sensor System and items of special support equipment employed with the Sensor for operational test purposes.

1. Flow-Direction and Pitot-Pressure Sensor, Nortronics P/N 5212138.
2. Sensor System Analyzer including electrical cables, Nortronics P/N 02580001.
3. Sensor Electrical Calibration Unit with electrical cable, Nortronics P/N 02580004.
4. Sensor Electronic Module Test Unit with electrical cables, Nortronics P/N 02580003.
5. Sensor Coupling and Support Fixture, Nortronics P/N 02580002.

III APPLICABLE DOCUMENTS

The following references contain background information relative to the design, operation, and test of the sensor:



1. N.A.S.A. Design Specification L8534A, dated October 21, 1957.
2. First Quarterly Engineering Report, NORT 58-28, dated March, 1958.
3. Second Quarterly Engineering Report, NORT 58-49, dated June, 1958.
4. Third Quarterly Engineering Report, NORT 58-79, dated September, 1958.
5. Fourth Quarterly Engineering Report, NORT 58-117, dated December, 1958.
6. Summary Test Report, NORT 59-142, dated October, 1959.
7. Installation Drawing - Flow-Direction Sensor, North American Aviation, Inc. Drawing 240-951510G.
8. Process Specifications - Flow Angularity Test, Installation, and Operation, North American Aviation, Inc., Specification EL4-248, dated 26 August 1958, revised 27 November 1959.
9. N.A.C.A. TN 3344, dated December 1954.

IV SENSOR TECHNICAL DESCRIPTION

The technical information presented in the following sections is applicable specifically to Sensor P/N 5212138, Serial Nos. 003, 004, 005, and 006.

1. General Features

1.1 α and β Measurement



The N.A.S.A. Sensor measures and transmits synchro output signals proportional to true angle of attack, α , and true angle of sideslip, β , during the high altitude and high speed flight missions of the X-15. These signals supply the aircraft attitude input measurement for the operation of the following aircraft equipment:

1. Angle of Attack Indicator N.A.A. P/N 25285-304
2. Angle of Sideslip Indicator N.A.A. P/N 25295-304
3. N.A.S.A. Recorder P/N LDZ 32487
4. Director Control P/N WCLCI-1-70A

1.2 Thermocouple Instrumentation

Thirteen chromel-alumel instrumentation thermocouples are located within the Sensor to electrically measure selected internal skin temperatures during flight. Five additional chromel-alumel thermocouples measure selected internal equipment temperatures. These signals are supplied to a N.A.S.A. furnished recorder aboard the aircraft.

1.3 Total Pressure Source

A total pressure source from the Sensor is supplied to the aircraft through an 0.375 inch diameter pressure line.

1.4 Inflight Test

A test circuit is provided for inflight check of the Sensor operation. This test is initiated by a push button switch in the pilot's compartment.



1.5 Cooling System

Expanded liquid nitrogen from the aircraft supply is used to cool and temperature condition the internal Sensor equipment. Temperature sensors and valves within the Sensor automatically control the coolant flow.

1.6 Ground Preflight Checkout

An electrical test connector accessible with the Sensor installed on the aircraft is provided for ground checkout of the Sensor systems.

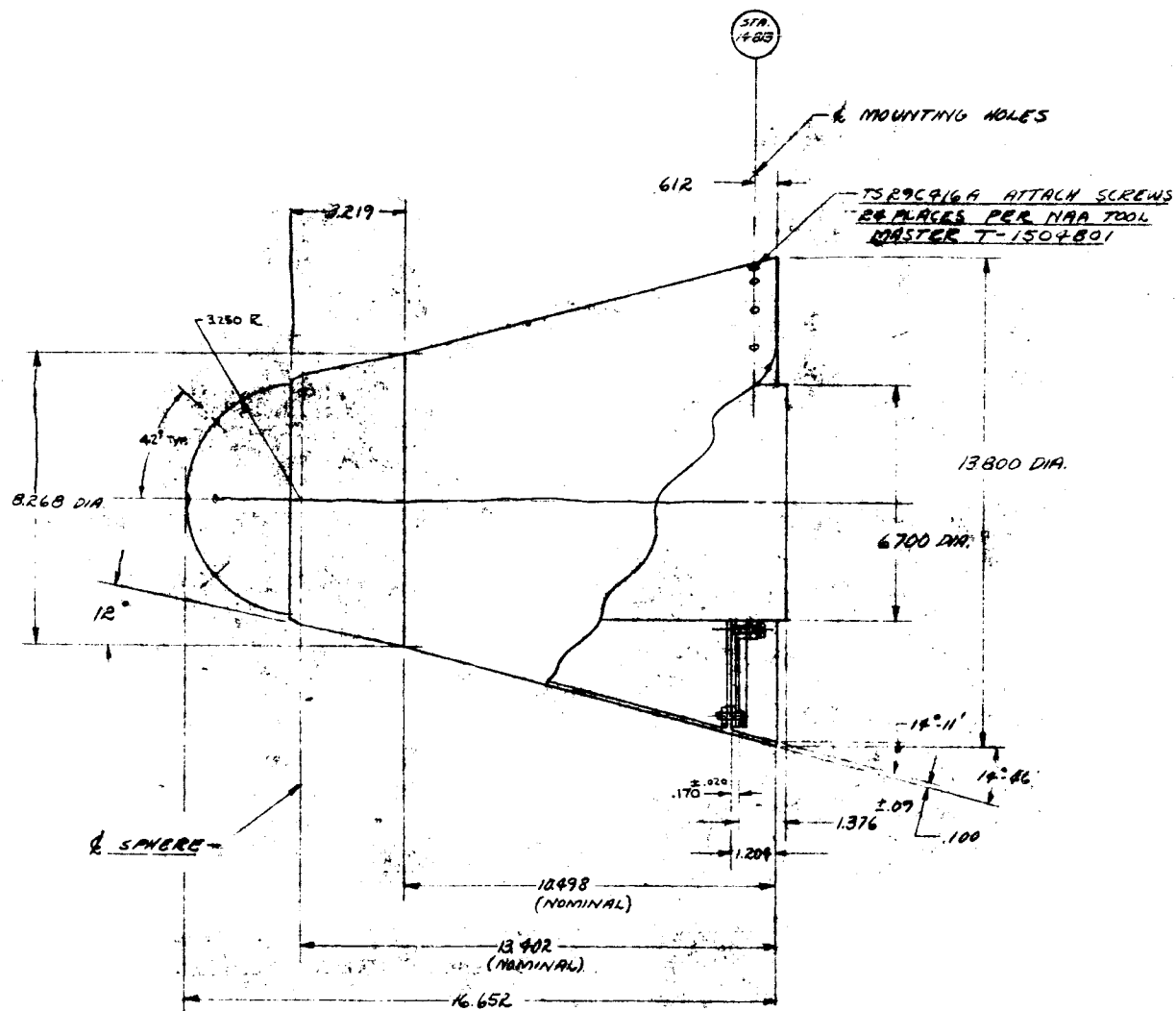
1.7 Installation

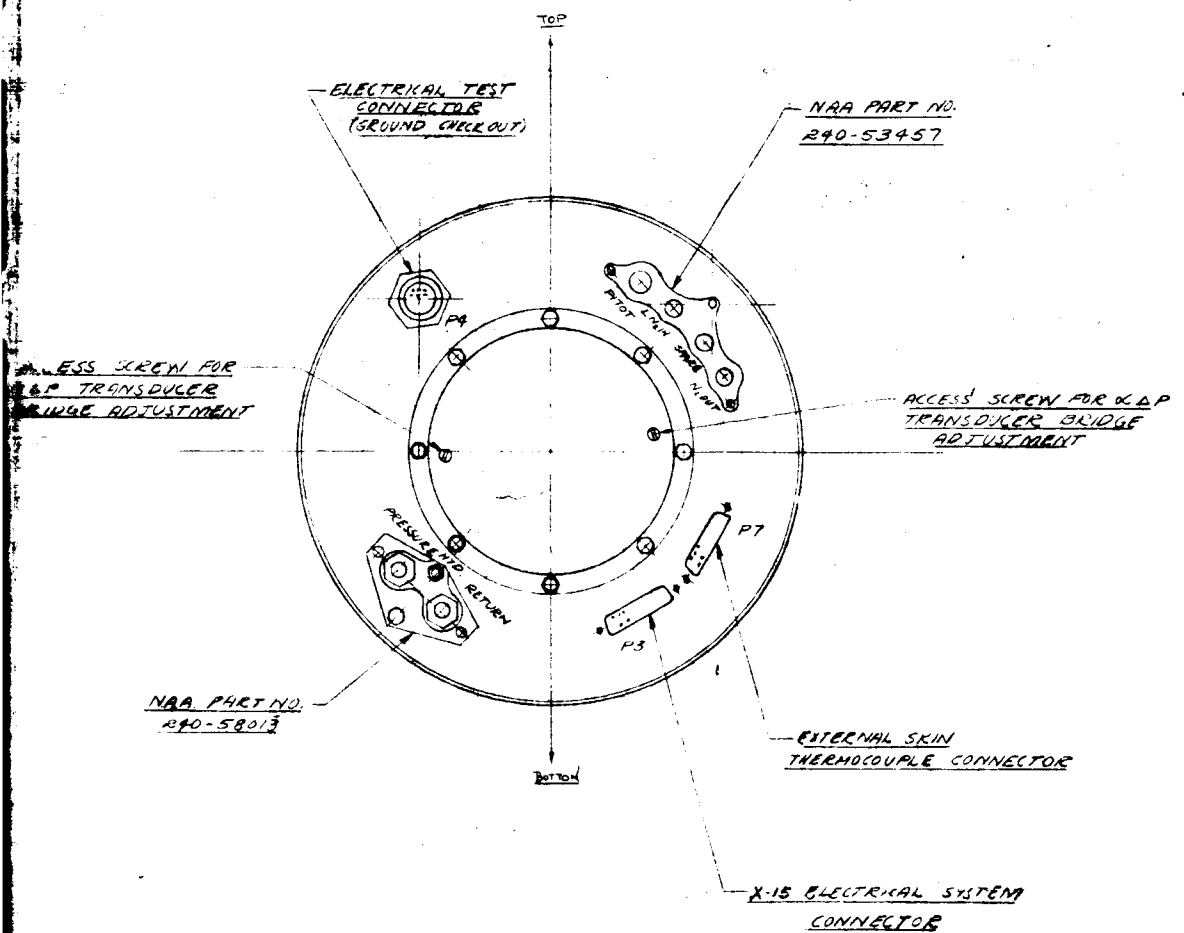
The N.A.S.A. Sensor is physically interchangeable with the boom nose (N.A.A. P/W LE 300404) of the X-15 aircraft. All connections to the Sensor are made through couplings which automatically engage when the Sensor is mounted on the aircraft. A diagram giving the locations and identity of the Sensor half of these couplings is shown in Figure 1. Further details describing the aircraft installation are given on N.A.A. drawing 240-951510.

1.8 Power Requirements

The Sensor receives electrical and hydraulic power and liquid nitrogen coolant from the aircraft supplies. Total Sensor supply requirements are as follows:

1. 115 ± 10 volts 400 cycle electrical power at 30 watts.
2. 28 ± 4 volts D.C. electrical power with 3.0 amps. peak.
3. 3000 ± 100 p.s.i. hydraulic power, 0.25 G.P.M. max.,
Oronite 8515 at -65°F to 400°F filtered to 10 microns.





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FIGURE 1

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4. Liquid nitrogen at 70 ± 5 p.s.i.

1.9 Weight

The total weight of the Sensor Assembly is 78 lbs. The weight of the combined Inconel-X outer skins (lip, cone, and sphere) account for approximately 50% of this total.

2. Principle of Operation

The Sensor external geometry consists of a 6.5 inch diameter servoed sphere mounted tangentially to a conical afterbody of approximately 15 degrees semi-vertex angle. Two pairs of 0.188 diameter orifices are located in the sphere each 42 degrees from the stagnation point, one pair in the vertical plane (α orifices) and one pair in the horizontal plane (β orifices). Two functionally identical servo systems are used to rotate the Sensor sphere about the α and β axes. These servos function to drive the sphere to a position such that the impact pressures seen by all sensing orifices are equal. When this condition exists, the sphere is oriented directly into the relative wind. Two synchros are used, one on the α sphere axis and one on the β sphere axis to measure the angular position of the sphere with respect to the structural cone afterbody. These angular measurements are then a true measure of the aircraft angle of attack and angle of sideslip.

A 0.5 inch diameter orifice located at the sphere stagnation point provides a total pressure source for the aircraft. This total



pressure measurement is also utilized within the Sensor for gain compensation in the α and β sphere servo systems. A schematic diagram showing the principle of Sensor operation is given in Figure 2.

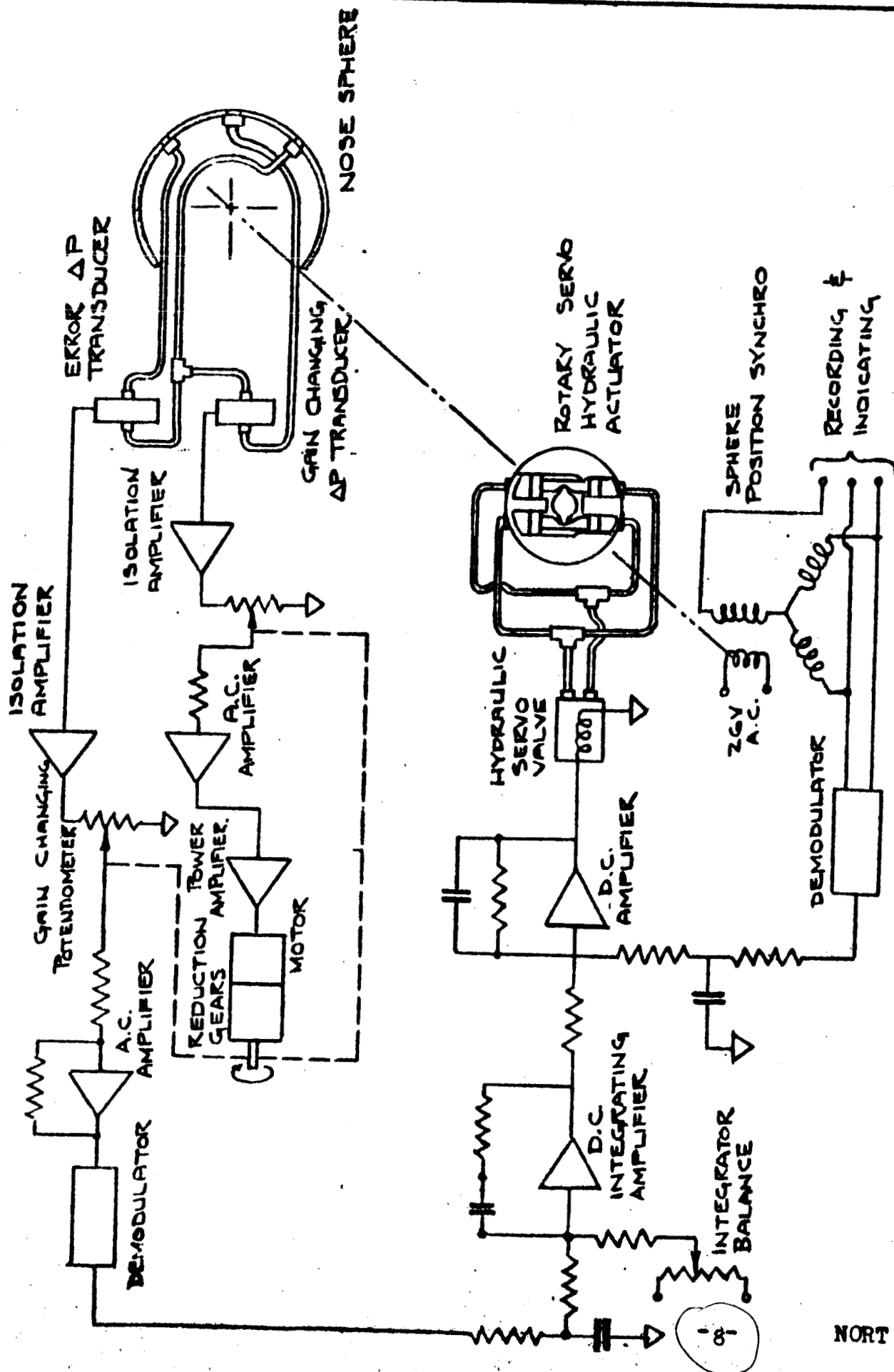
3. Sensor Physical Description

3.1 Servo System

The α and β servo systems are functionally identical. These systems are mechanized as shown in Figure 3, with an inner positional servo loop which in turn is controlled by an outer, unity feedback, differential pressure control loop. The outer loop functions to drive to zero the differential pressure measured across either pair of sphere sensing orifices.

Because the differential pressure gain of the sphere sensing orifices with respect to sphere angular displacement relative to the wind vector is directly proportional to the dynamic pressure, q , of the airstream, a single instrument servo is used for gain compensating both servo loops according to the function $1/q$. This gain changing servo is programmed by a differential pressure measurement made between the sphere stagnation orifice and the right β orifice.

The nominal loop error voltage levels, the error voltage polarity, the location of the system test points, and the D.C. gain and saturation levels of the servo system components are shown also on Figure 3.

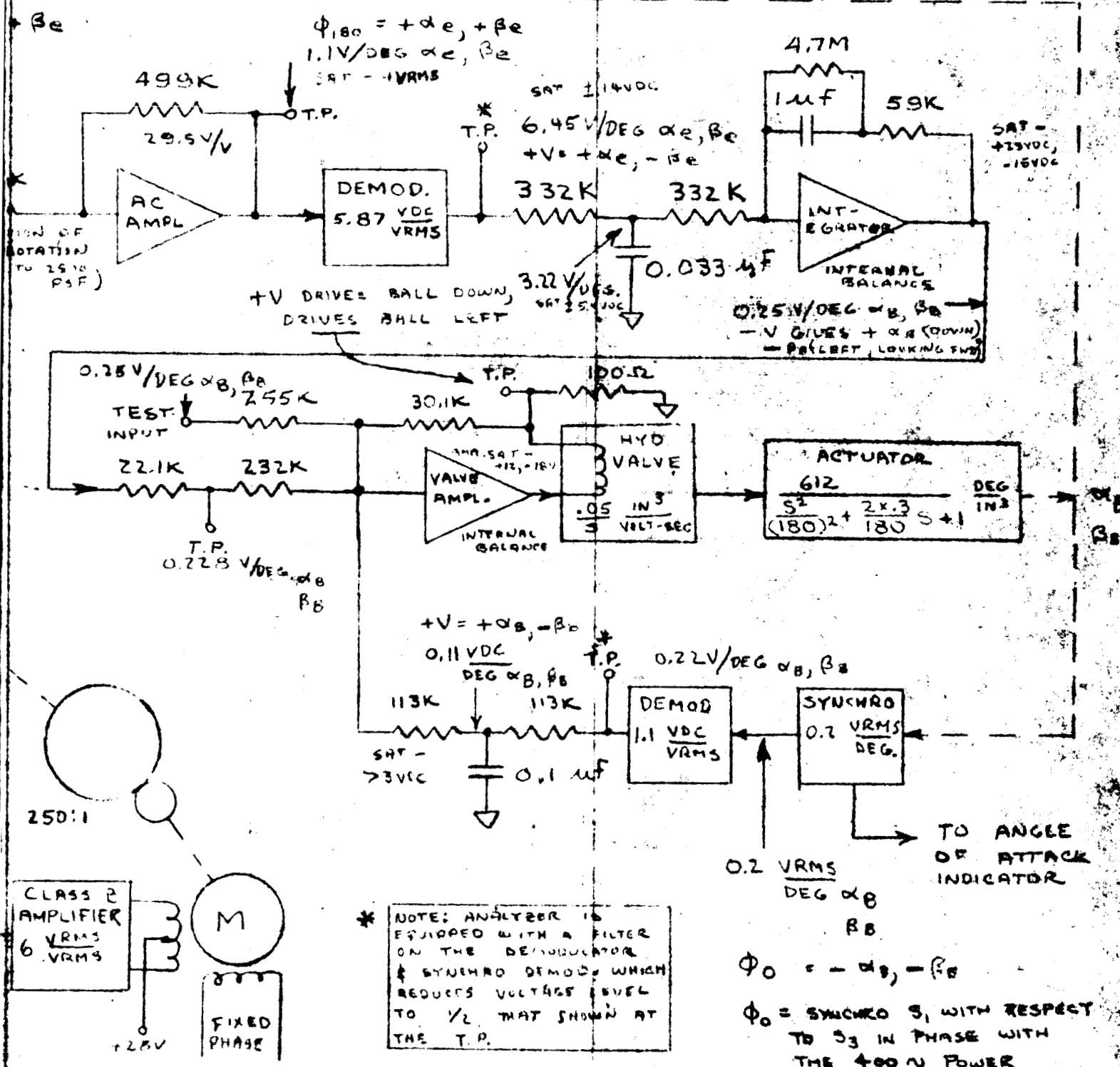


α or β SERVO MECHANIZATION SCHEMATIC - FIGURE 2.

NORT 60-46



FIGURE 3



NASA FLOW-DIRECTION & PITOT PRESSURE SENSOR

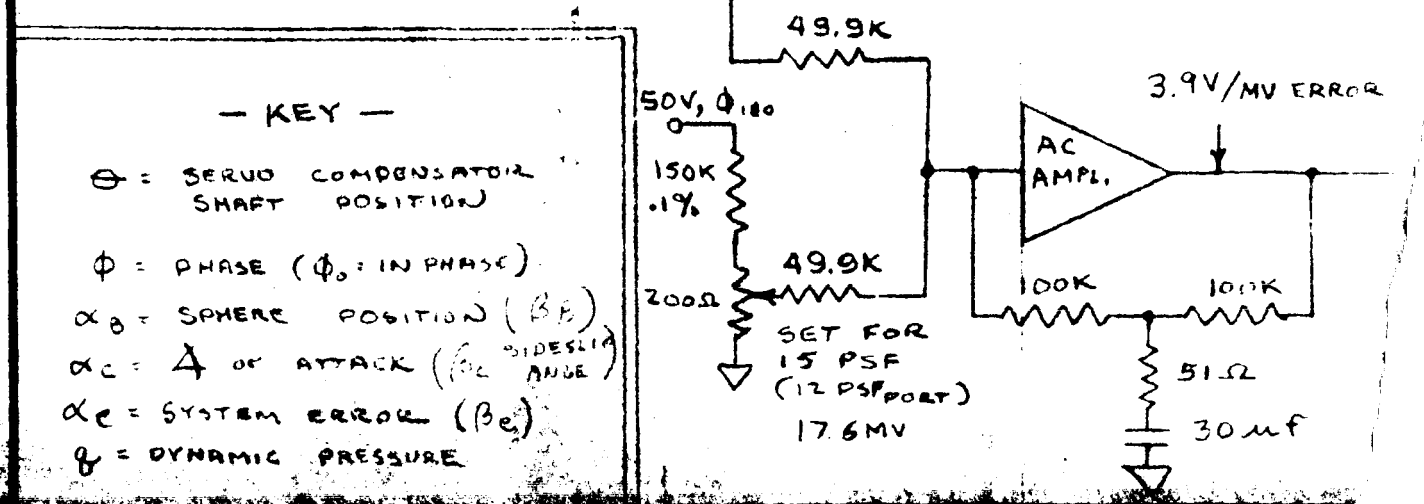
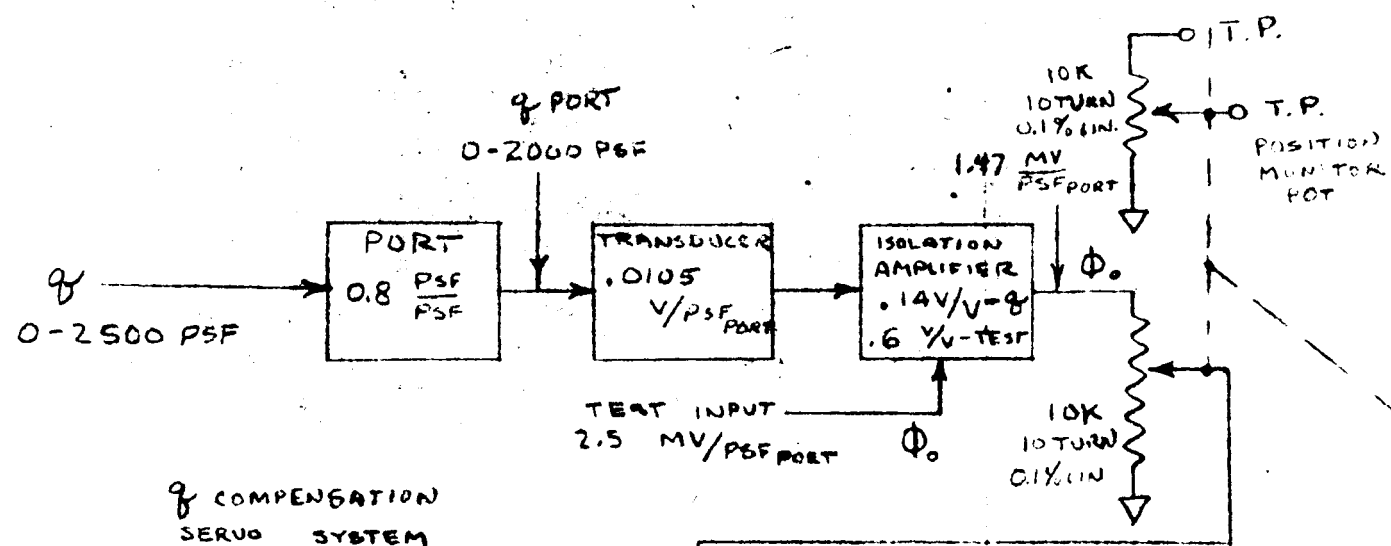
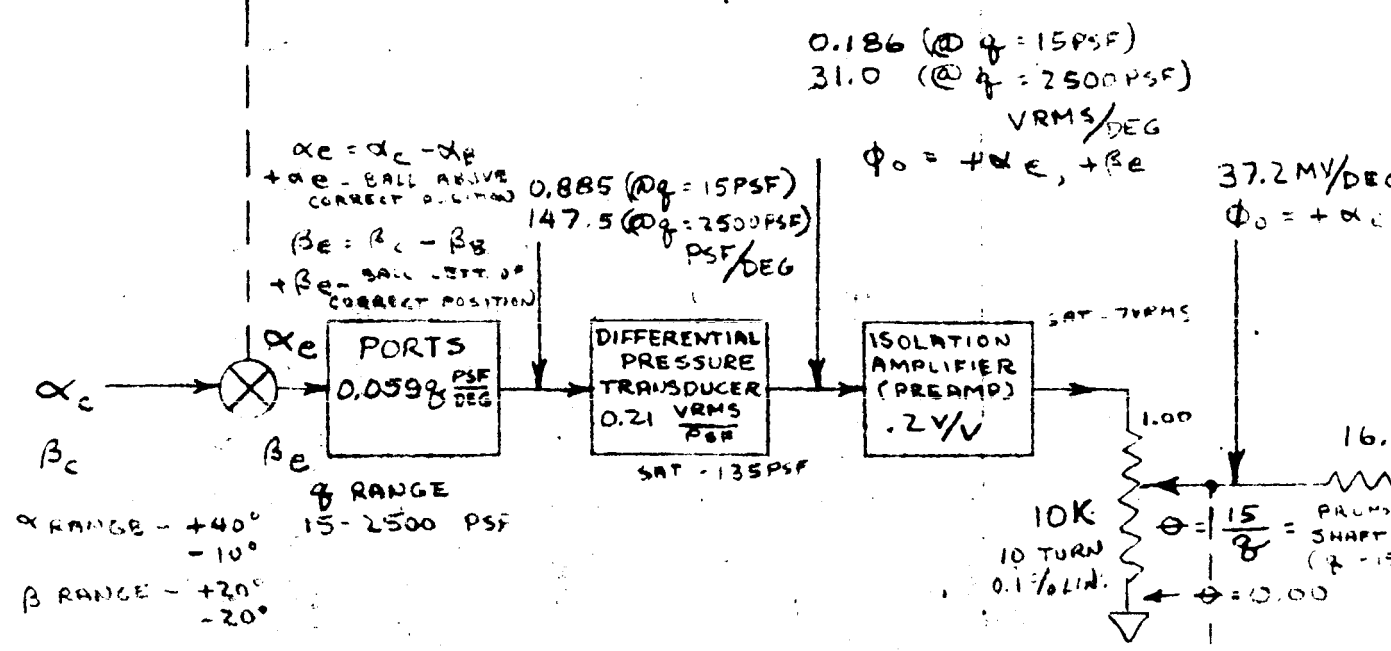




Figure 4 shows a servo block diagram of either the α or β loop with the component transfer functions assigned.

The servo electronic circuit elements, the α and β differential pressure error transducers, the gain changing transducer, and the gain changing servo assembly are all housed within the Electronic Controller Assembly P/N 5212171. A drawing of this assembly is shown in Figure 5.

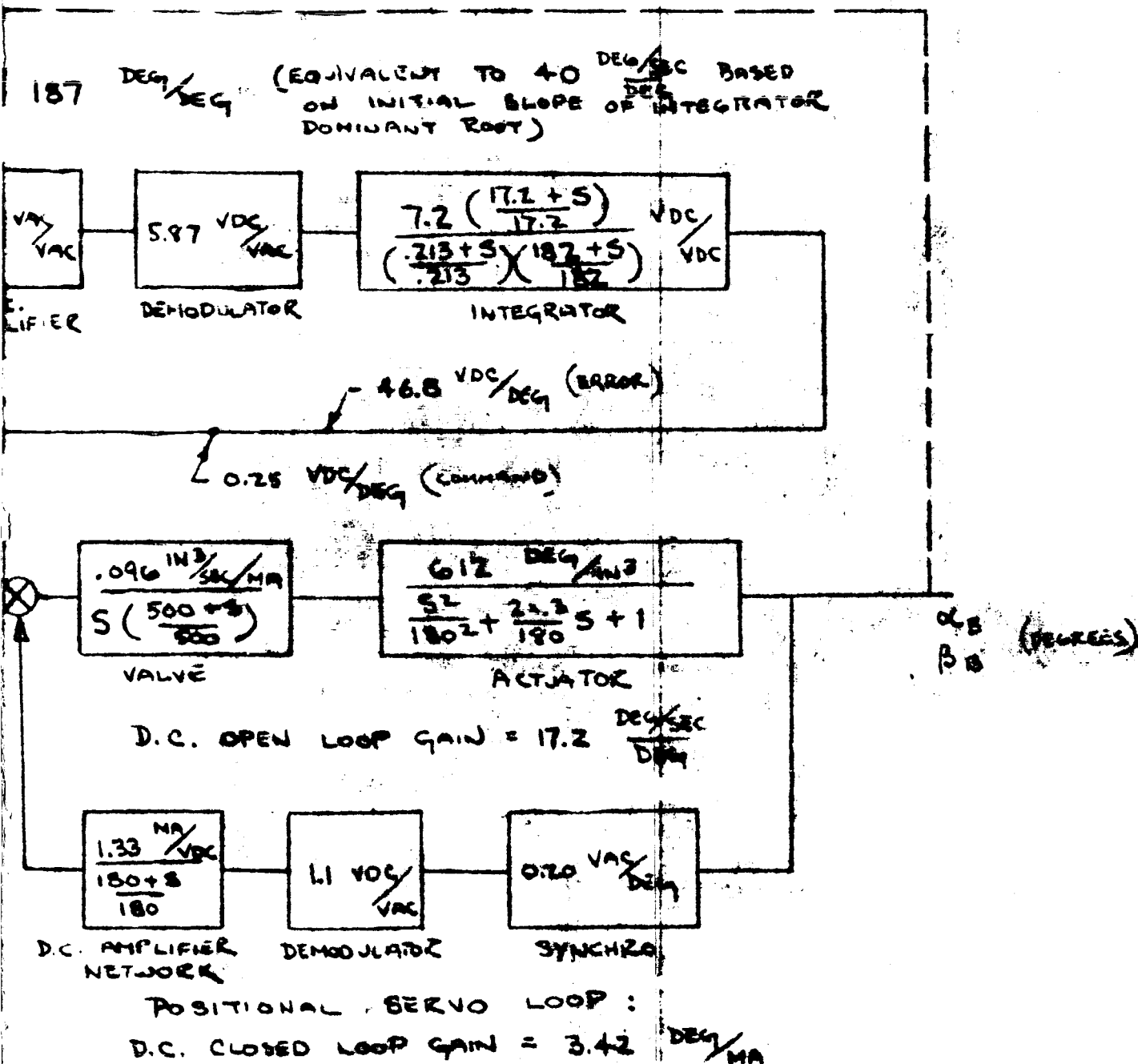
The electronic circuit elements of the α and β servo axes are assembled on printed circuit boards P/N 4212175 and form decks 1 and 2 respectively of the Electronic Controller Assembly. A schematic wiring diagram showing either the α or β servo electronic circuits is given in Figure 6. The physical location of the circuit elements shown on this diagram may be obtained from the α or β Circuit Board Assembly, drawing 4212175.

A third printed circuit deck of the Electronic Controller Assembly contains the circuit associated with the gain changing servo, elements of the power supply, and the electrical relays of the Sensor cooling systems. A schematic wiring diagram of these circuits is given in Figure 7; the location of the circuit elements on the circuit board may be obtained from the q Compensation Circuit Board Assembly, drawing 4212197.

A fourth deck segment located between the β servo board and the q deck contains the printed circuit and electronic elements associated with the inflight test and elements of the sphere and cone temperature

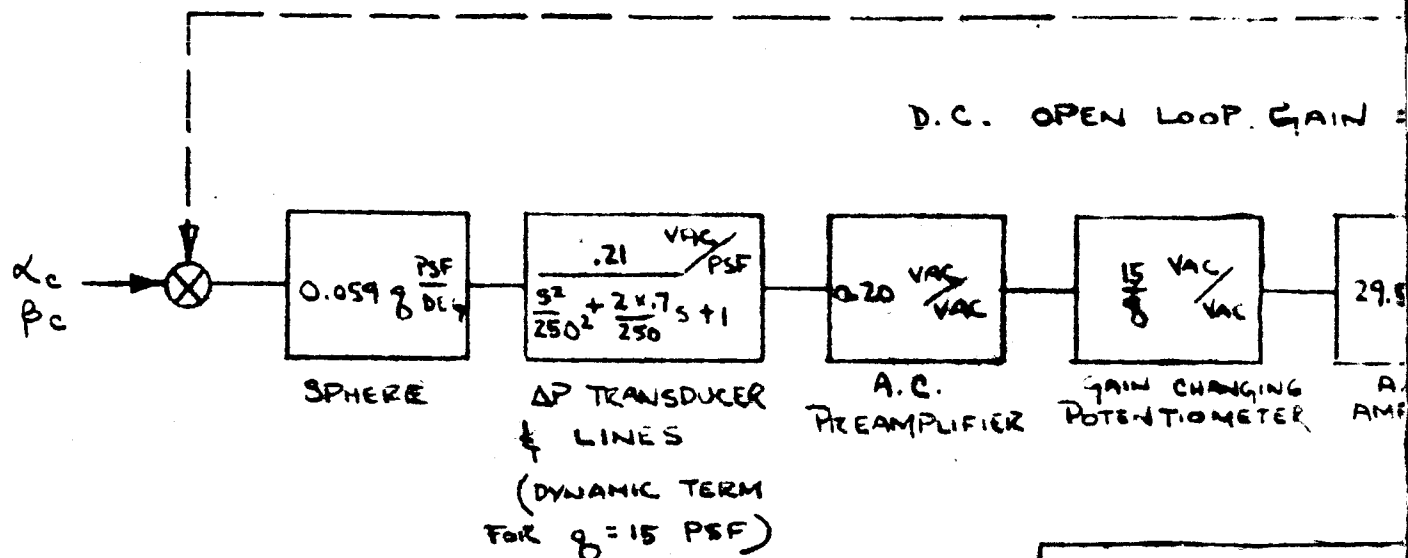
ENGINEER	NORTHROP AIRCRAFT, INC. NORTHROP DIVISION	PAGE 11
REVIEWER		REPORT NO. NOET 60-46
DATE SEPT. 30 '59	SERVO BLOCK DIAGRAM	MODEL

FIGURE 4



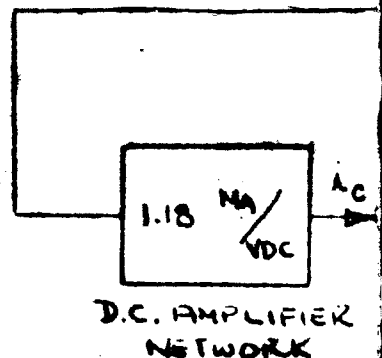
CLOSED OUTER LOOP TRANSFER FUNCTION:

$$\frac{\alpha_B, \beta_B}{\alpha_c, \beta_c} = \frac{187/188 \text{ DEG/DEG}}{\left(\frac{s^2}{240^2} + \frac{2 \times 8}{240} s + 1\right) \left(\frac{s^2}{175^2} + \frac{2 \times 5}{175} s + 1\right) \left(\frac{s^2}{70^2} + \frac{2 \times 3}{70} s + 1\right)}$$



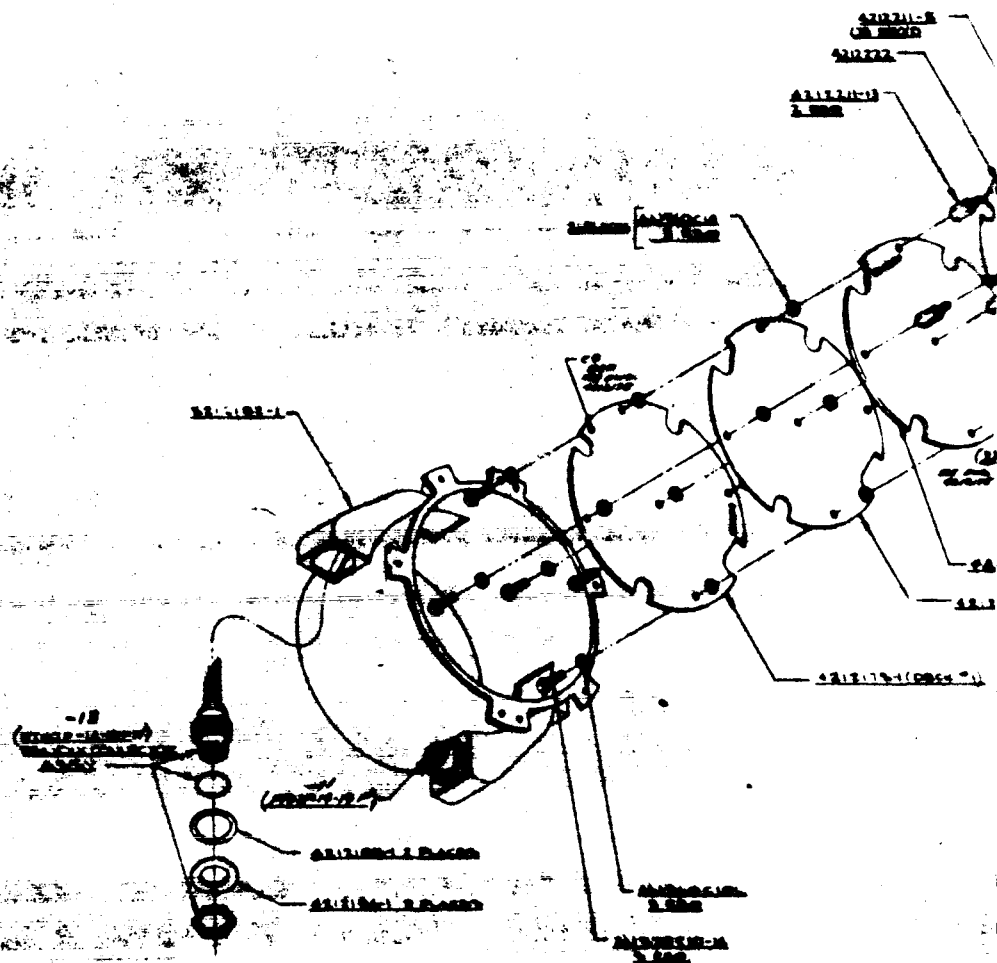
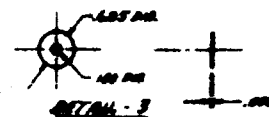
CLOSED POSITIONAL LOOP TRANSFER FUNCTION:

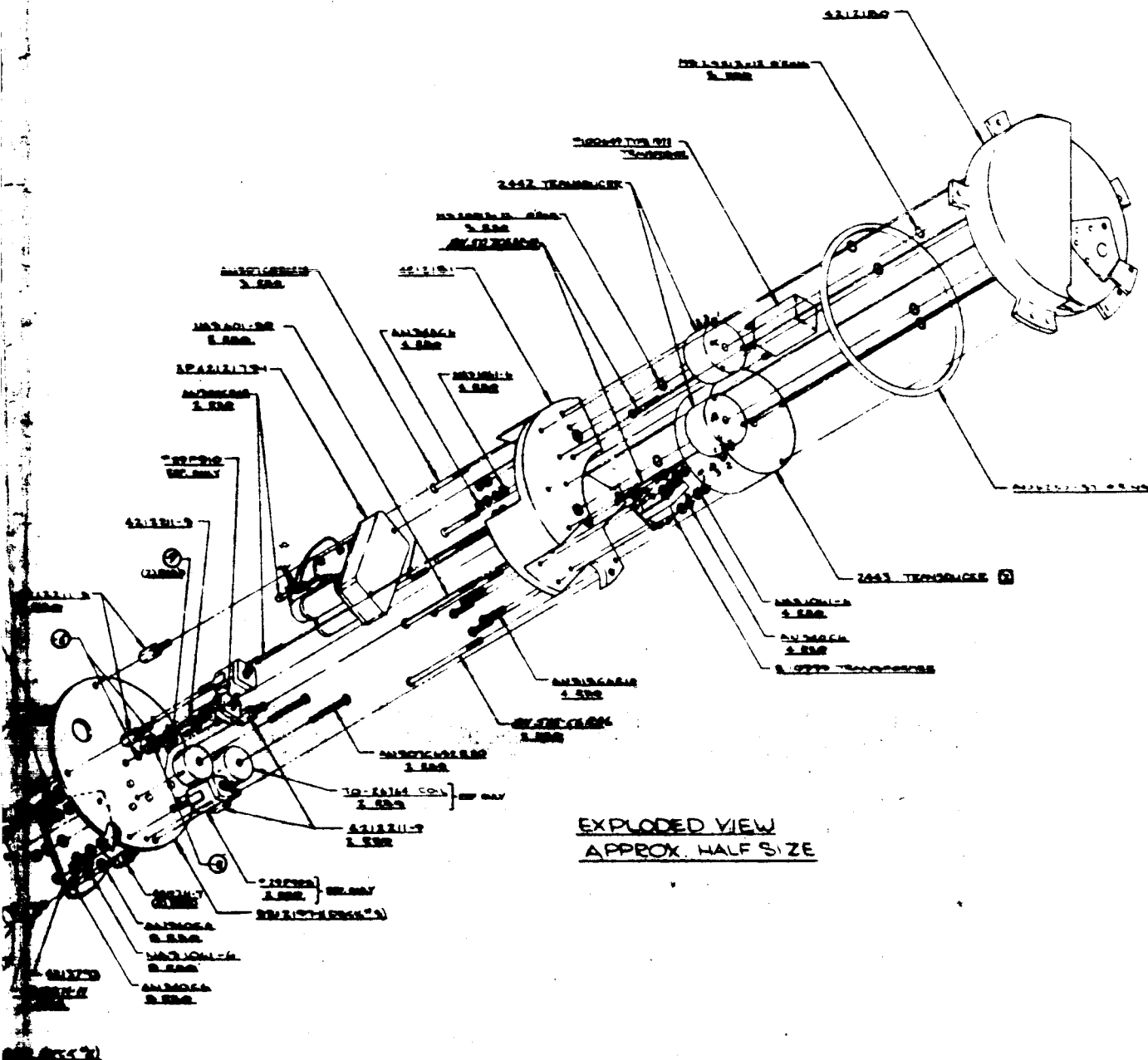
$$\frac{\alpha_B, \beta_B}{I_a} = \frac{3.42 \left(\frac{180+s}{180}\right) \text{ DEG/MA}}{\left(\frac{20+s}{28}\right) \left(\frac{s+500}{500}\right) \left(\frac{s+160}{160}\right) \left(\frac{s^2}{170^2} + \frac{2 \times 3}{170} s + 1\right)}$$



CODE:

- g DYNAMIC PRESSURE (P.S.F.)
- s LAPLACE OPERATOR
- β ANGLE OF SIDESLIP AXIS
- α ANGLE OF ATTACK AXIS
- I_a CURRENT COMMAND TO POSITIONAL LOOP
- α_B, β_B SPHERE ANGULAR POSITION
- α_c, β_c OUTER LOOP COMMAND MOTION OF THE AIRCRAFT



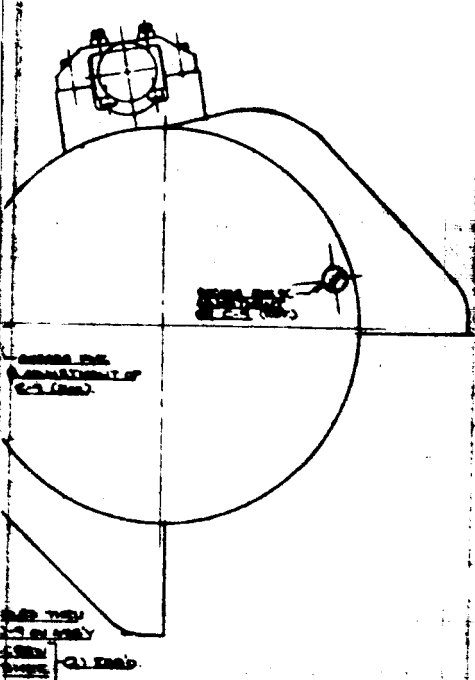
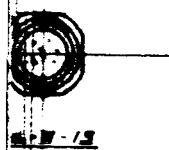


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FIGURE 5

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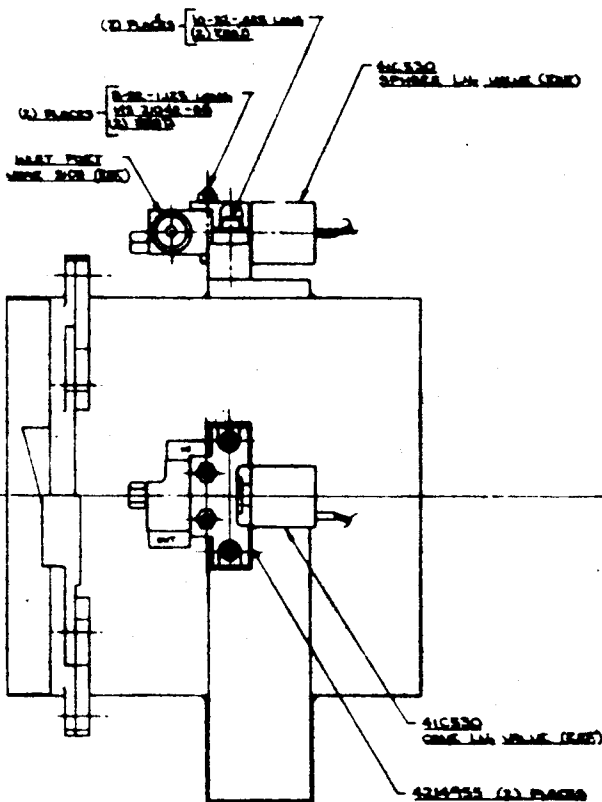


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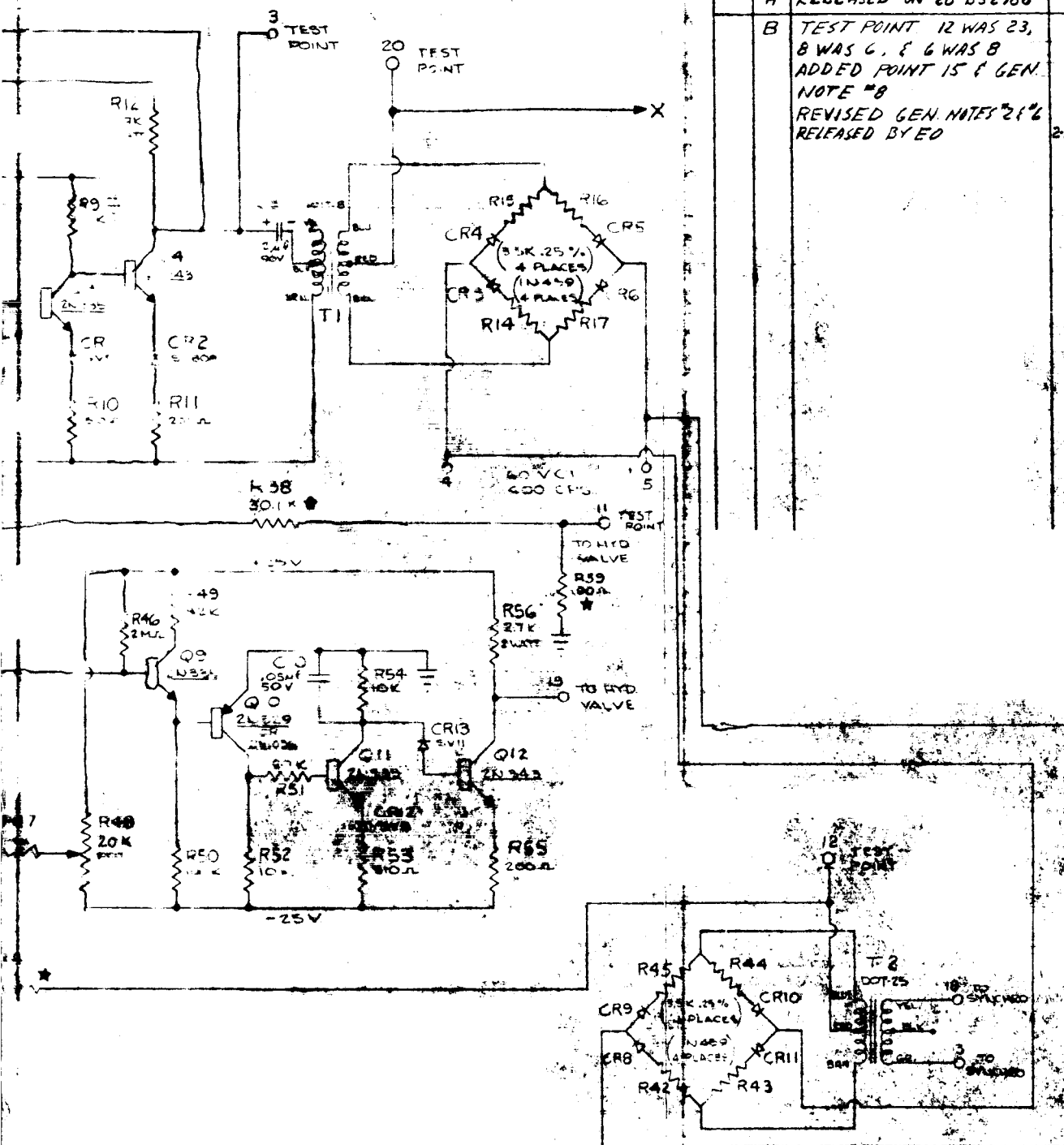
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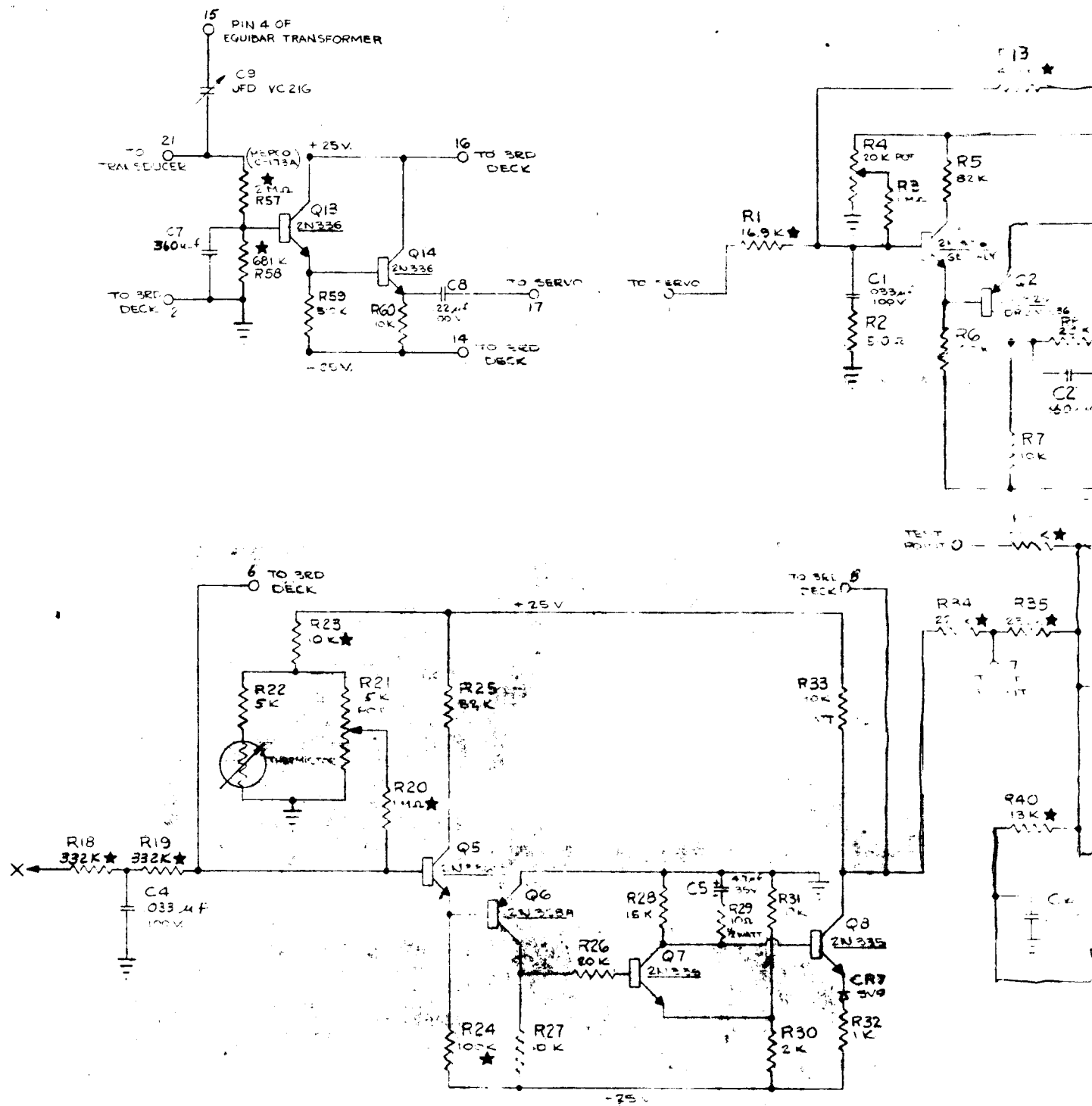
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UNLESS OTHERWISE SPECIFIED		INDICATES SURFACE ROUGHNESS PER MIL-STD-10		DRAWING TITLE		THIS DRAWING AND INFORMATION PROPERTY OF, AND UNAUTHORIZED REPRODUCTION, FORSHEEN BY NORTHROP AIRCRAFT, INC. NORTHROP DIVISION NORTHROP CORP., CALIF. ODD DASH NO. SHOWN, EVEN ODD		SHEET NO.									
QTY REQD PER ASSY		PART NUMBER		DESCRIPTION		MATERIAL		SIZE		MATERIAL SPEC & PROC DATA		DRAWING TITLE		THIS DRAWING AND INFORMATION PROPERTY OF, AND UNAUTHORIZED REPRODUCTION, FORSHEEN BY NORTHROP AIRCRAFT, INC. NORTHROP DIVISION NORTHROP CORP., CALIF. ODD DASH NO. SHOWN, EVEN ODD		SHEET NO.	
UNLESS OTHERWISE SPECIFIED		INDICATES SURFACE ROUGHNESS PER MIL-STD-10		DRAWING TITLE		THIS DRAWING AND INFORMATION PROPERTY OF, AND UNAUTHORIZED REPRODUCTION, FORSHEEN BY NORTHROP AIRCRAFT, INC. NORTHROP DIVISION NORTHROP CORP., CALIF. ODD DASH NO. SHOWN, EVEN ODD		SHEET NO.									



8. R21 & R22 MAY BE DIFFERENT VALUES CALLED OUT TO PROVIDE CORRECT SERVO MOTOR OPERATION.
7. ALL RESISTORS 1/4 WATT 5% TOL.
6. ★ INDICATES 1% TOL. RESISTORS.
5. ALL RESISTOR TOLERANCES ARE 5%.
4. ALL WIRE IS ENAMELED.
3. ALL CAPACITORS BETWEEN 100V AND 50V ARE SILVER MICA.
2. 0 INDICATE CONNECTIONS TO GROUND.
1. THERMISTOR IS VECO 37A.

NOTES: UNLESS OTHERWISE SPECIFIED

DISPOSITION PARTS MADE		REVISIONS		3. OK TO USE
		1. MAY BE REWORKED	2. CANNOT BE REWORKED	4. RECORD CHANGE
ZONE	SYN	DESCRIPTION	DISP & DATE	EFFECTIVE ON
	A	RELEASED ON EO B52788	11-3-79 R.S.	
	B	TEST POINT 30 WAS 23 REVISED GEN NOTE "A" RELEASED BY EO	2-26-80	W/ ELL:104



PAGE 14



control systems. A schematic diagram of these circuits is also given in Figure 7 and the location of the circuit elements on the circuit board may be obtained from the Circuit Board Assembly - Fail Warning and Temperature Control, drawing 4213793.

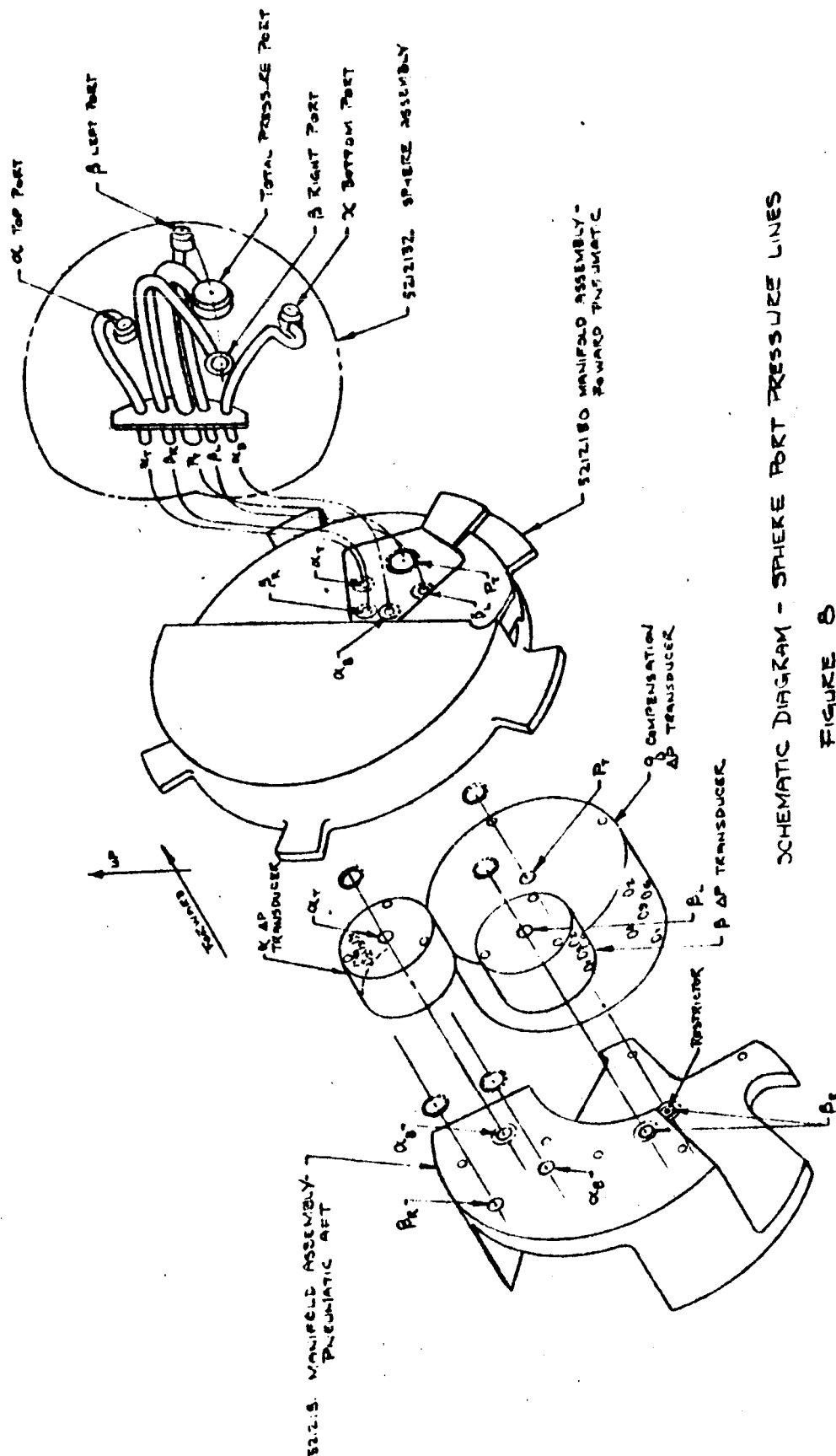
Pressure inputs from the sphere sensing orifices are made through the manifold at the forward end of the Electronic Controller Assembly. Figure 8 shows schematically the routing arrangement and connection of these pressure lines.

3.2 Electrical System

The electrical wiring diagram showing electrical pin connections, wire identification, and connector identification for the general Sensor electrical system is shown in Figure 9.

3.3 Hydraulic System

The α and β rotary hydraulic actuators, the prime movers of the servo system, are packaged as an integrated mechanism within the Sensor sphere. All hydraulic fluid transfer to and from the actuators is accomplished by integral porting within the actuator housings and support structure. The fluid transfer to each actuator is controlled by an electrohydraulic servo valve mounted and ported by a common manifold. A hydraulic filter integral with the hydraulic manifold provides fluid filtration to 10 microns per MIL-F-5504A. Figure 10 shows a schematic diagram of the hydraulic portion of the Sensor system. The detail assembly is shown on the



SCHEMATIC DIAGRAM - SPHERE PORT PRESSURE LINES

FIGURE 8

FOR THE PURPOSES OF THIS DRAWING, THE FOLLOWING ASSUMPTIONS ARE MADE:

THE DRAWING IS A REPRESENTATION OF THE ACTUAL SITUATION AND NOT A GUARANTEE OF THE ACCURACY OF THE INFORMATION CONTAINED HEREIN.

THE DRAWING IS A REPRESENTATION OF THE ACTUAL SITUATION AND NOT A GUARANTEE OF THE ACCURACY OF THE INFORMATION CONTAINED HEREIN.

TABLE 1: SUMMARY OF DATA

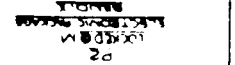
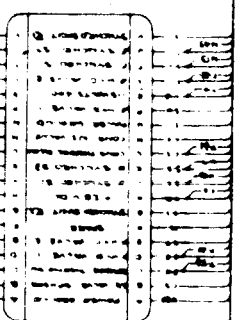
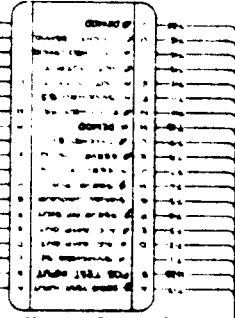
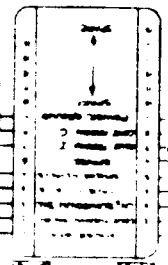
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2	ITEM 2	UNIT 2	2.0
3	ITEM 3	UNIT 3	3.0
4	ITEM 4	UNIT 4	4.0
5	ITEM 5	UNIT 5	5.0
6	ITEM 6	UNIT 6	6.0
7	ITEM 7	UNIT 7	7.0
8	ITEM 8	UNIT 8	8.0
9	ITEM 9	UNIT 9	9.0
10	ITEM 10	UNIT 10	10.0

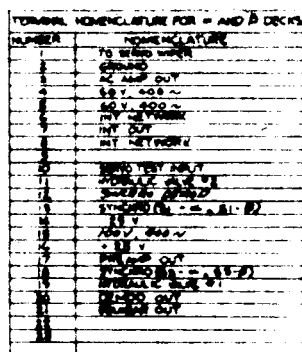
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THE DRAWING IS A REPRESENTATION OF THE ACTUAL SITUATION AND NOT A GUARANTEE OF THE ACCURACY OF THE INFORMATION CONTAINED HEREIN.

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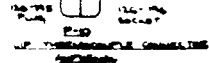
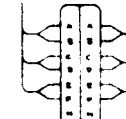
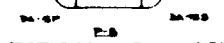
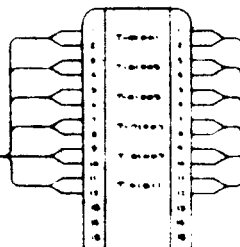
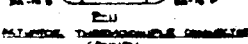
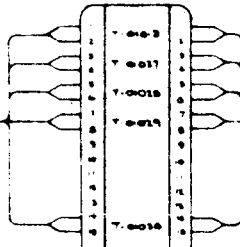
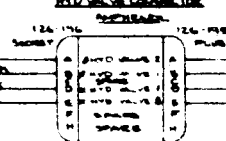
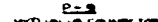
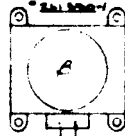
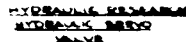
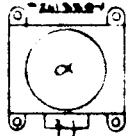
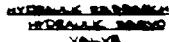
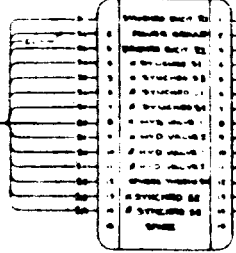
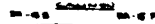
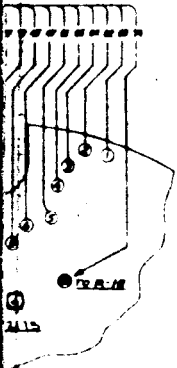
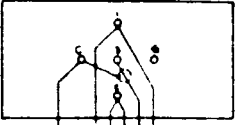


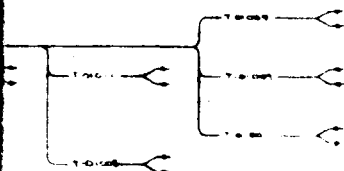


" THESE COPIES WERE THE ONLY
 " THESE COPIES WERE MADE WHEN THEY WERE IN THE
 " ALL THESE, ONE & TWO THESE COPIES
 " EXCEPT T-ONE AND MAKE THREE OF THEM
 " THERE IS AN OUTSIDE OF WATER COOL UNIT.

5212223

LEADERSHIP
1999
2000





- [illegible]

Figure 10

Q. Did you find that the fluid moved to the actuator moves spoke up?

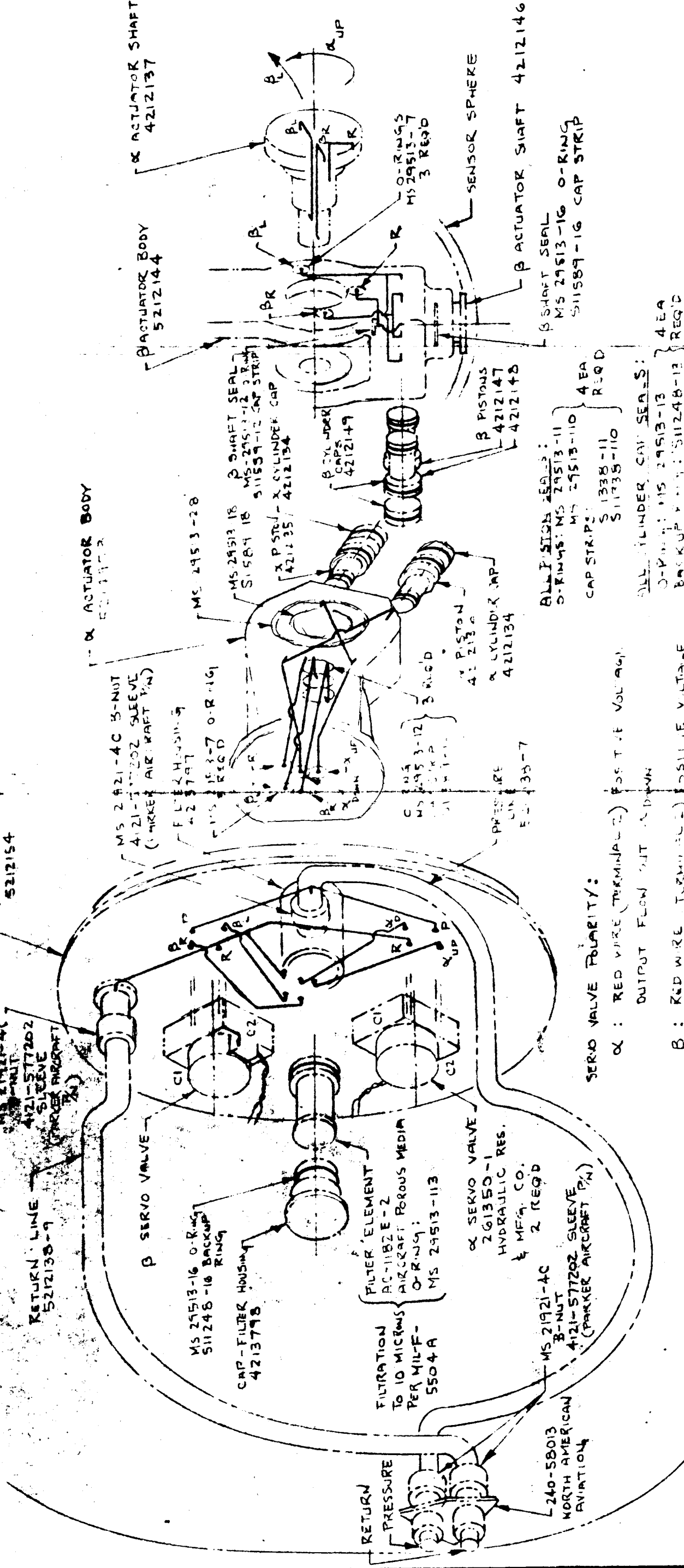
DOWN: FLUID FLOW TO ACTUATOR MOVES "PICK" DOWN

α Down: Fluid Flow to β Actuator Moves SPHERE RIGHT } (LOOKING FWD.)
 β : Fluid Flow to β Actuator Moves SPHERE RIGHT } (LOOKING FWD.)

3. Fluid Flow To A Actuator

MS 21921-4C 7
HYDRAULIC MANFOLD ASSY
5212154

RETURN LINE
5212138-9
421-517202
SLEEVE



SERVO VALVE POLARITY:

 α : RED VOLTAGE (TERMINAL-2) POSITIVE VOLTAGE.

OUTPUT FLOW 'IT - 2 DAY

B: RED WIRE TURNING (-) POSITIVE VOLTAGE

OUTPUT FLOW OUT

Schematic Diagram - Hydraulic System



Sphere Actuation Assembly, drawing 5212143, of Figure 10A. Note that all hydraulic O-ring seals use compound 363-70 of the Plastics and Rubber Products Company.

3.4 Cooling System

A schematic diagram of the cooling system arrangement is shown in Figure 11. A wiring schematic is shown on Figure 11A. Separate temperature control and coolant distribution systems are used for conditioning the environment within the cone and within the sphere. In each system low temperature nitrogen is taken from the shipboard supply, throttled through an on-off solenoid operated control valve and allowed to flow through the distribution system. The cone distribution system utilizes a cold wall contiguous with the cone insulation. LN₂ is introduced at the rear and gaseous N₂ exhausted at the front. The sphere distribution system directs gaseous N₂ at the areas where the β actuator shaft and the β synchro shaft attach to the sphere.

Each system uses a disc type thermistor to sense the existing internal temperature and to actuate the respective LN₂ valve relay. The cone thermistor is located in the N₂ exhaust of the cone cold wall. The sphere thermistor is housed in the β actuator shaft. The valve relays are mounted on the q Compensation Circuit Board, P/N 4212197, in the Electronic Controller Assembly.

ENGINEER

PAGE

21

CHECKER

NORTHROP AIRCRAFT, INC.

REPORT NO.

4-17-51

MODEL

NORTH 60-46

CONE LN₂ INLET COUPLING
P/N 4214957

CONE LN₂ VALVE
CROCKER MFG. P/N 410530
MS 21902-4 C UNION (2 REQ)
AN 6290-4 O-RING (2 REQ) USE
PARCO COMPOUND 363-70

CONE LN₂ LINE
P/N 5212138-3

BLOWDOWN SWITCH
KELIXON P/N MI-015-15-252

BLOWDOWN SWITCH MTING BRACKET
P/N 4214960

LN₂ FILTER ASSEMBLY
P/N 4214950
AN 6290-4 O-RING
(PARCO COMPOUND 363-70)

SPHERE LN₂ LINE

SPHERE LN₂ VALVE
CROCKER MFG. P/N 410530
MS 21902-4 C UNION
AN 6290-4 O-RING (PARCO
COMPOUND 363-70)
COUPLING ASSEMBLY
NORTH AMERICAN AVIATION, INC.
P/N 240-53457

SPHERE LN₂ LINE
P/N 5212138-5

MS 21908-4 ELBOW
AN 6290-4 NUT
MS 21917-4 PACKING RING
AN 6290-4 O-RING (USE PARCO COMPOUND 363-70)

LN₂ LINE
P/N 5212138-5

MS 21908-4 ELBOW

SPHERE LN₂ DISTRIBUTOR
P/N 5212155

SPHERE THERMISTOR TEMPERATURE PROBE
P/N 4214959

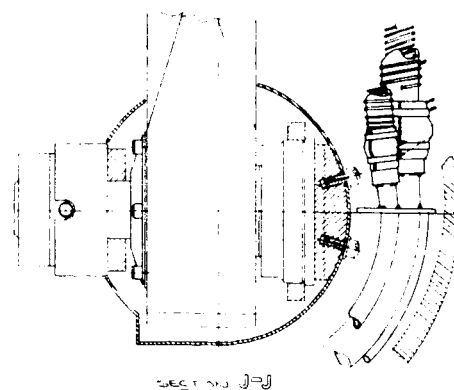
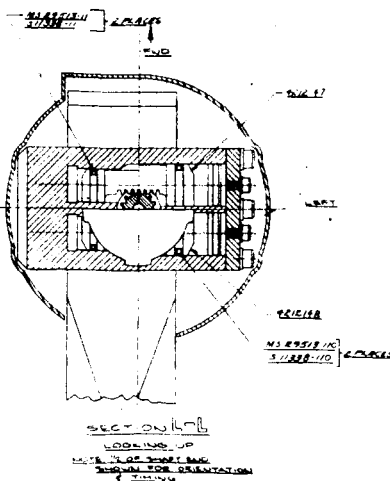
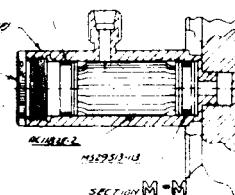
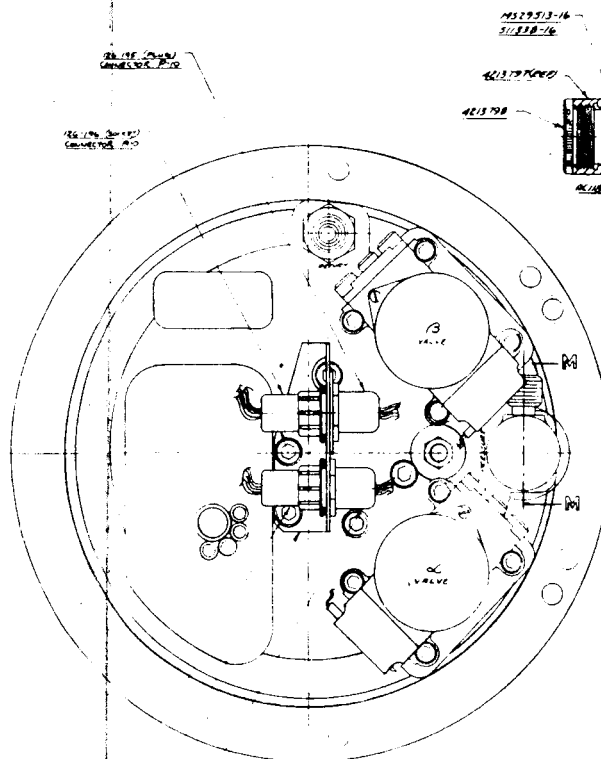
CONE TEMPERATURE PROBE
P/N 4213515

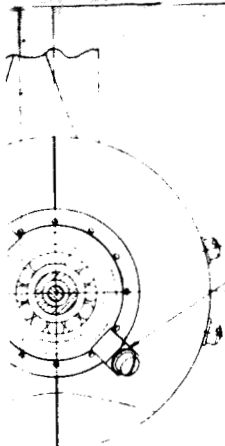
CONE TEMPERATURE PROBE
P/N 4212194

CONE TEMPERATURE PROBE
P/N 4212193

FIGURE 11

COOLING SYSTEM - MECHANIZATION DIAGRAM NEW LOOKING DOWN





1920 CLAMP
 6-32 X 1/2 INCH NUT 6-32 X 1/2 INCH WASH. WITH 6-32 X 1/2 INCH WASHER
 4-32 X 1/2 INCH NUT 4-32 X 1/2 INCH WASHER
 4-32 X 1/2 INCH WASHER
 4-32 X 1/2 INCH WASHER

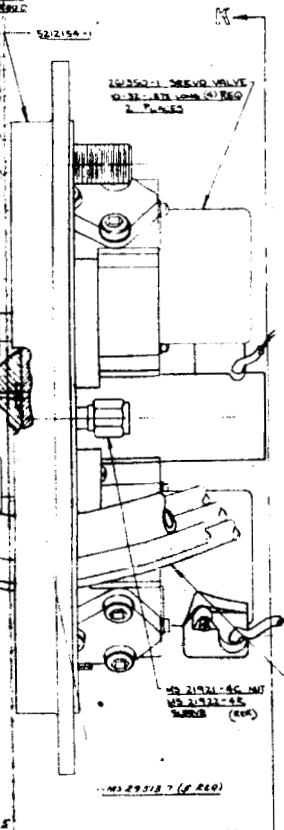
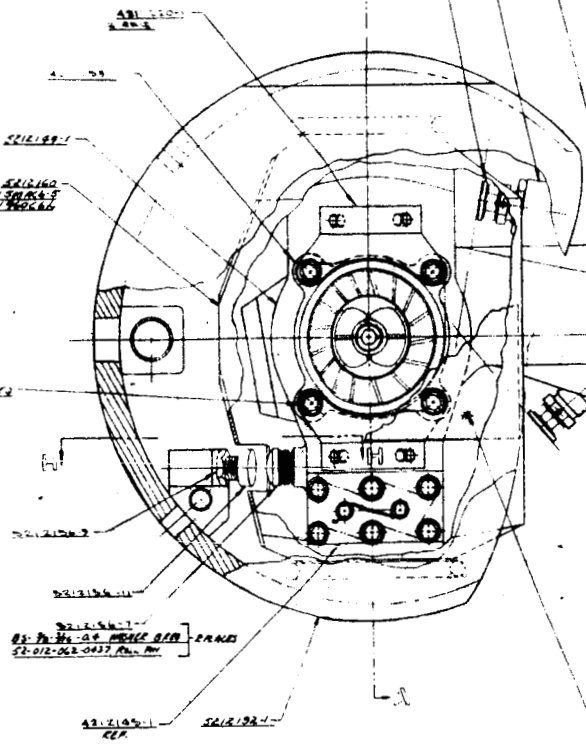
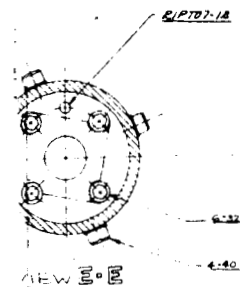
4-32 X 1/2 INCH WASHER

4-32 X 1/2 INCH WASHER
 4-32 X 1/2 INCH WASHER
 4-32 X 1/2 INCH WASHER
 4-32 X 1/2 INCH WASHER

VIEW F F
 4-32 X 1/2 INCH WASHER
 4-32 X 1/2 INCH WASHER
 4-32 X 1/2 INCH WASHER
 4-32 X 1/2 INCH WASHER

4-32 X 1/2 INCH WASHER
 4-32 X 1/2 INCH WASHER

VIEW E E
 4-32 X 1/2 INCH WASHER
 4-32 X 1/2 INCH WASHER



1. 4-32 X 1/2 INCH WASHER 4-32 X 1/2 INCH WASHER 4-32 X 1/2 INCH WASHER 4-32 X 1/2 INCH WASHER
2. 4-32 X 1/2 INCH WASHER 4-32 X 1/2 INCH WASHER 4-32 X 1/2 INCH WASHER 4-32 X 1/2 INCH WASHER
3. 4-32 X 1/2 INCH WASHER 4-32 X 1/2 INCH WASHER 4-32 X 1/2 INCH WASHER 4-32 X 1/2 INCH WASHER
4. 4-32 X 1/2 INCH WASHER 4-32 X 1/2 INCH WASHER 4-32 X 1/2 INCH WASHER 4-32 X 1/2 INCH WASHER
5. 4-32 X 1/2 INCH WASHER 4-32 X 1/2 INCH WASHER 4-32 X 1/2 INCH WASHER 4-32 X 1/2 INCH WASHER
6. 4-32 X 1/2 INCH WASHER 4-32 X 1/2 INCH WASHER 4-32 X 1/2 INCH WASHER 4-32 X 1/2 INCH WASHER
7. 4-32 X 1/2 INCH WASHER 4-32 X 1/2 INCH WASHER 4-32 X 1/2 INCH WASHER 4-32 X 1/2 INCH WASHER
8. 4-32 X 1/2 INCH WASHER 4-32 X 1/2 INCH WASHER 4-32 X 1/2 INCH WASHER 4-32 X 1/2 INCH WASHER
9. 4-32 X 1/2 INCH WASHER 4-32 X 1/2 INCH WASHER 4-32 X 1/2 INCH WASHER 4-32 X 1/2 INCH WASHER
10. 4-32 X 1/2 INCH WASHER 4-32 X 1/2 INCH WASHER 4-32 X 1/2 INCH WASHER 4-32 X 1/2 INCH WASHER

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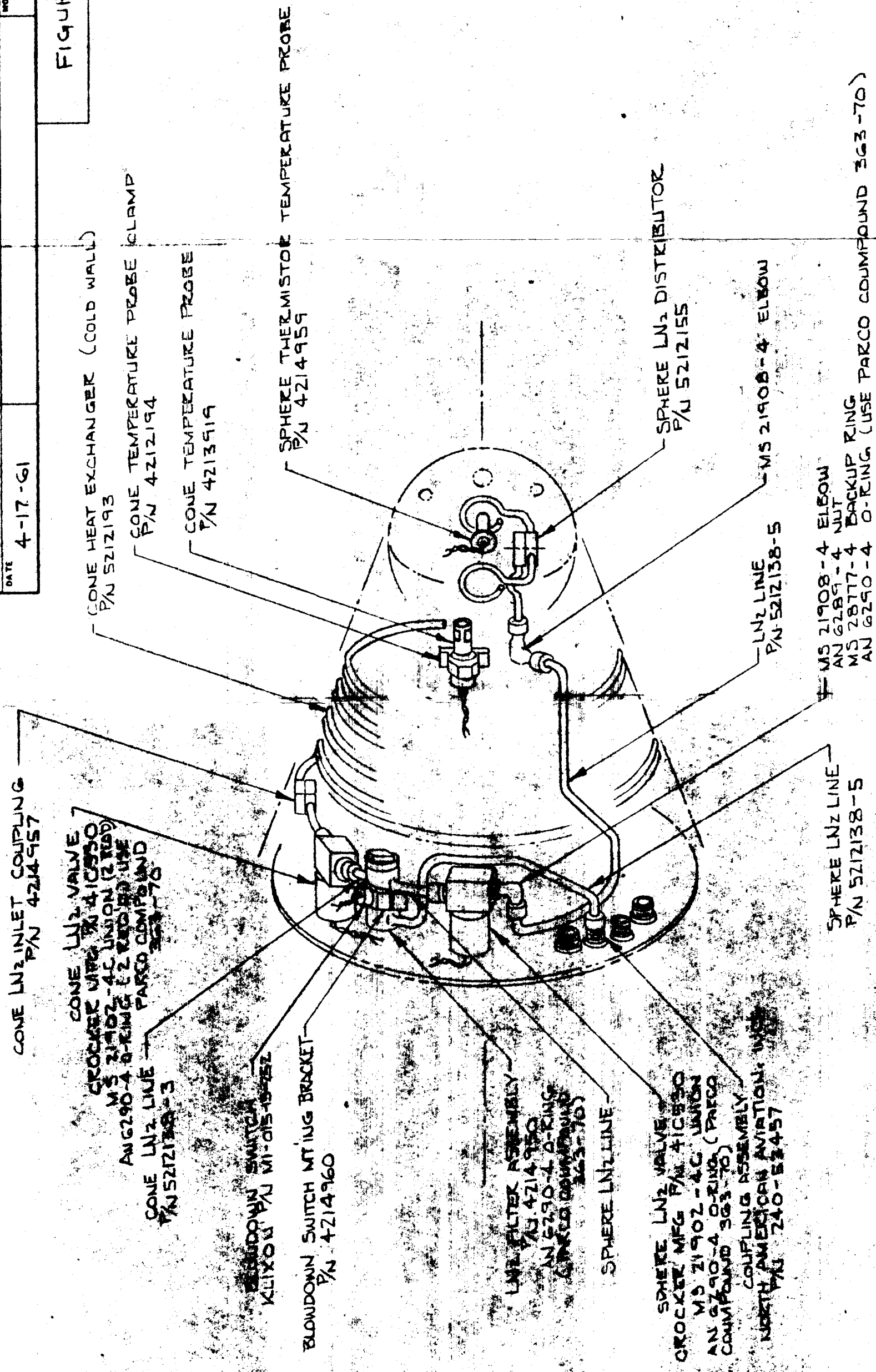
A transistorized circuit associated with each thermistor is used to increase the thermistor signal power sufficient to operate the sphere and cone LN₂ valve relays. This circuit is mounted on the Fail Warning and Temperature Control Circuit Board Assembly, P/N 4213793.

A third thermal switch connected directly across the cone LN₂ valve coil is mounted on the cone LN₂ filter body and is responsive to the filter body temperature. This switch is a bi-metal type and is used to provide intermittent blowdown of the LN₂ supply line such that the filter body and, therefore, the supply line are maintained at a low temperature. This blowdown arrangement assures immediate coolant flow to either the cone or sphere control valve in response to coolant command from either the cone or sphere thermistor circuit.

The electrical leads of both the sphere and cone thermistors are brought out at the Sensor test connector. These leads are provided for both actuating and monitoring the Sensor cooling systems during

ENGINEER	NORTHROP AIRCRAFT, INC.	PAGE	21
CHECKER		REPORT NO.	NORT 60-46
DATE		4-17-61	MODEL

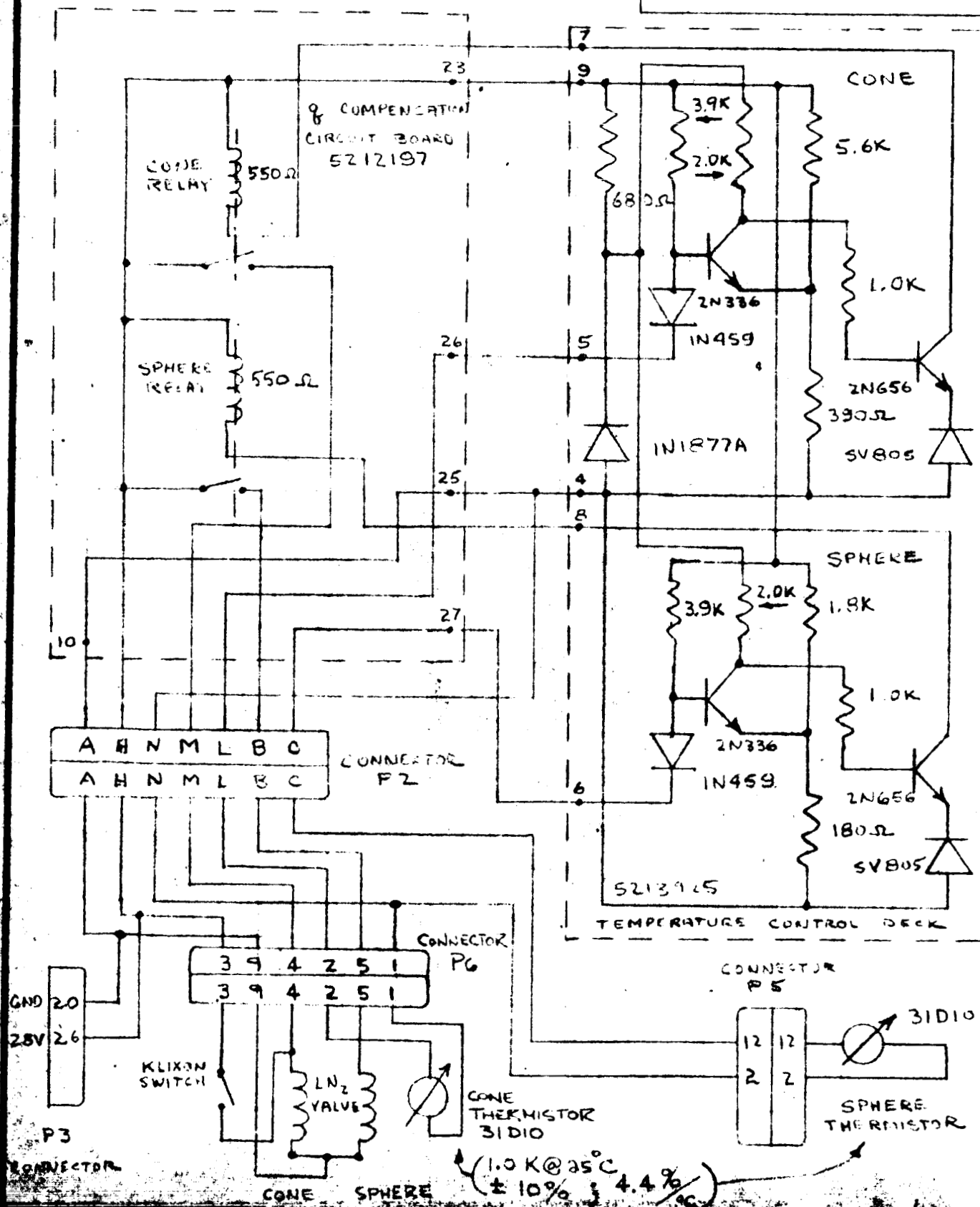
FIGURE 11



COOLING SYSTEM - MECHANIZATION DIAGRAM
VIEW LOOKING DOWN

ENGINEER	NORTHROP AIRCRAFT. INC. NORTHROP DIVISION	PAGE 22
CHECKER		REPORT NO. NORT 60-46
DATE 1-12-60	CIRCUIT DIAGRAM - SENSOR TEMPERATURE CONTROL SYSTEM	MODEL

FIGURE 11A





ground checkout procedures.

An iron-constantan test thermocouple is installed integrally with the cone thermistor with leads brought out to the Sensor test connector. This thermocouple permits measurement of the internal Sensor temperature through the Sensor System Analyzer during ground test procedures.

3.5 Inflight Test System

Inflight test of the Sensor is performed by momentarily closing the pilot's test switch. When this switch is closed, the error signals in the α and β differential pressure servo control loops are grounded at the output of the outer loop integrators and a fixed D.C. positional voltage command is applied to the input test point of the α and β positional servo loops. The positional command causes the sphere to rotate to a predetermined position in α and β . The response of the Sensor sphere to the test command is read by the pilot on the α and β indicators. The recovery characteristics of the Sensor sphere, upon release of the test switch, provide a check of the proper operation of the outer differential pressure control loops.

A schematic diagram of the test system is shown in Figure 12.

The circuit associated with the failure warning system is mounted on the Fail Warning and Temperature Control Circuit Board in the Electronic Controller Assembly.



The schematic diagram of this board is shown on Figure 7, and the physical location of the circuit elements may be obtained from the Failure Warning and Temperature Control Circuit Board Assembly, drawing 4213793.

4. Sensor Operating Characteristics

The following information is included to provide a summary of Sensor operational data:

4.1 Range of Sphere Angular Travels

Angle of Attack, α : + 40 deg
 - 10 deg

Angle of Sideslip, β : \pm 20 deg

Adjustable stops within the Sphere Actuation Assembly, drawing 5212143, are used to limit and adjust the sphere travel. Over-travel of \pm 5 degrees is provided within the α and β actuators.

4.2 Electrical Zero and Polarity of the α and β Synchro Transmitters

Angle of Attack, α , Electrical Zero: + 15 deg

Angle of Sideslip, β , Electrical Zero: 0 deg

The electrical zero defined above assumes like phase on both transmitter and receiver synchro rotor leads, R_1 .

The α and β synchro polarities are defined as follows:

1. Increasing positive α results in clockwise rotation of Kearfott R-510 (or equivalent synchro receiver shaft when



viewed from shaft end.

2. Decreasing right rudder sideslip results in clockwise rotation of Kearfott R-510 (or equivalent) synchro receiver shaft when viewed from the shaft end.

The α and β synchro polarities stated above, when referenced to N.A.S.A. Recorder LDZ 32487, result in the following definition:

1. Increasing positive α (nose of sphere moving down) results in downward motion of the α light beam on Recorder LDZ 32487.
2. Decreasing right rudder sideslip (nose of the sphere moving right) results in downward motion of the β light beam on Recorder LDZ 32487.

4.3 Dynamic Pressure Range of Servo Gain Compensation

Maximum 2500 p.s.f.

Minimum 15 p.s.f.

The above compensation range is based upon an assumed pressure differential between the sphere total pressure port and the β right port equal to $0.8q$. Figure 2 of N.A.C.A. TN 3344 for $M = 3.80$, reproduced as Figure 12A of this report, shows the data on which this assumption is based.

4.4 Static Accuracy of Flow Angle Measurement

The static accuracy of flow angle measurement is better than 0.25 degrees. This accuracy applies to Sensor operation within the range

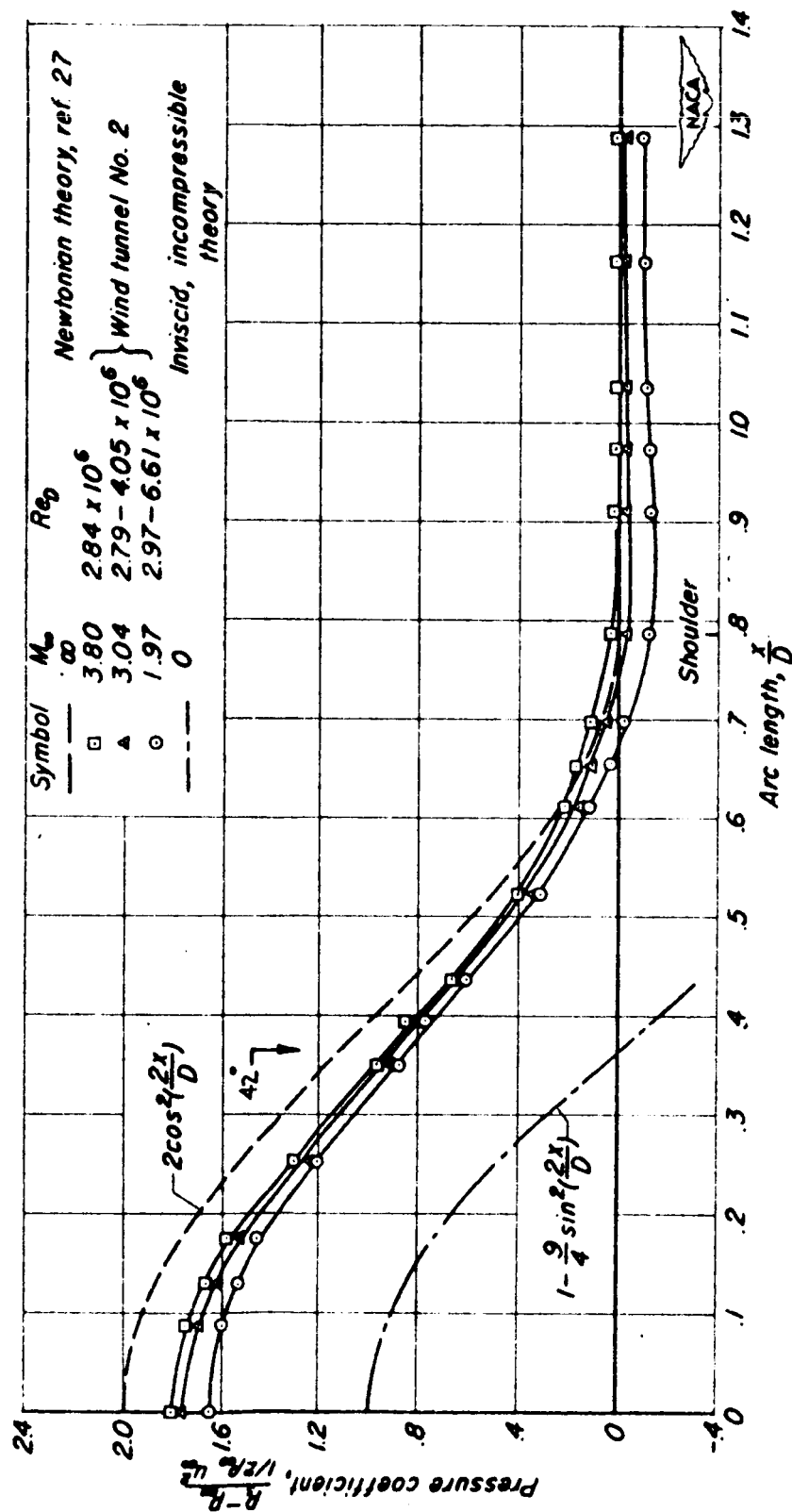


Figure 12A. Variation of Pressure Coefficient Along Spherical Surface
(Taken from NACA TN 3344)



of gain compensation (for dynamic pressures between 15 and 2500 p.s.f.). Figure 13 shows an error analysis covering operation over an extended range of dynamic pressure.

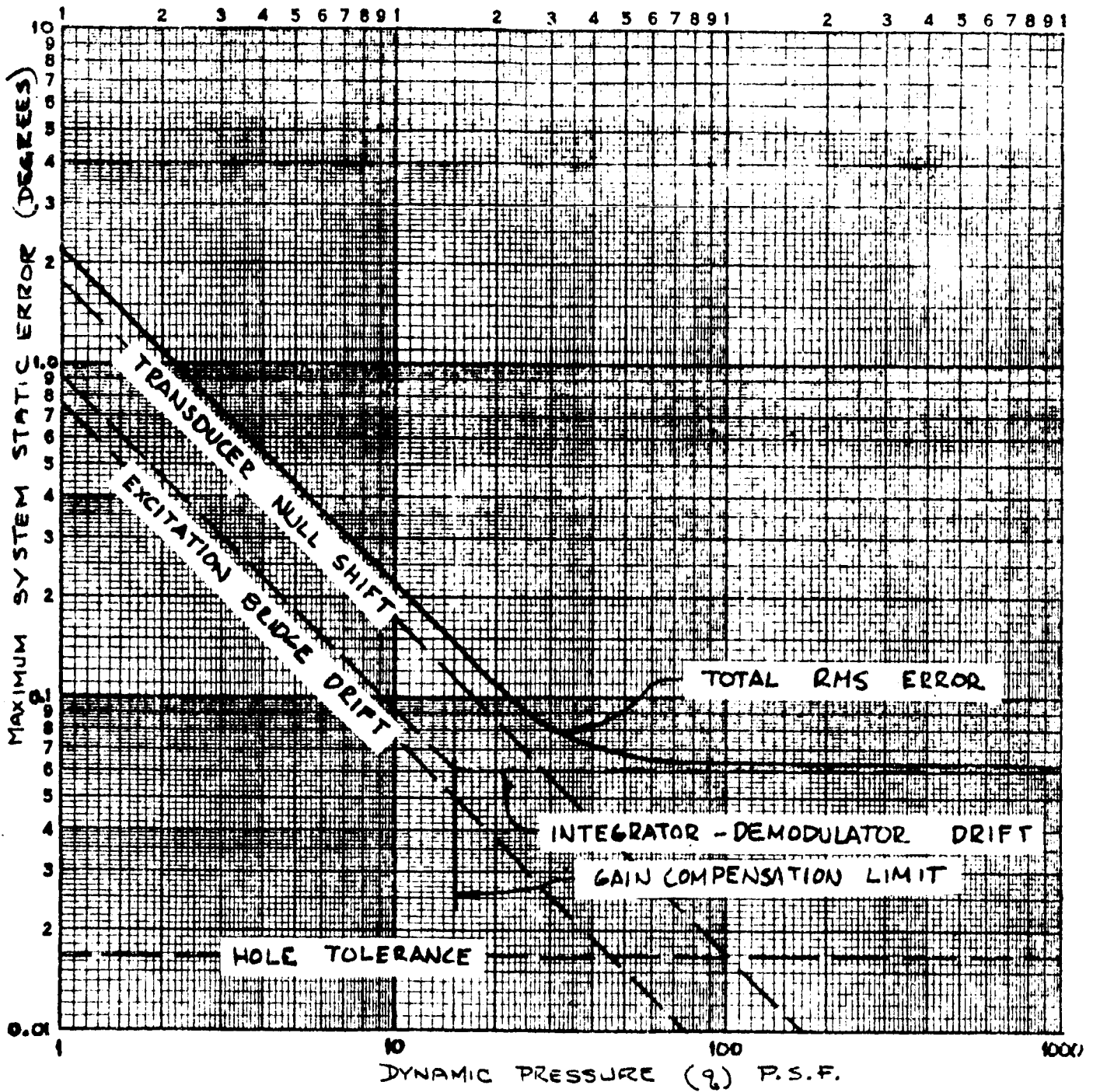
The actual magnitude of the total position error is temperature dependent. The error analysis shown on Figure 13 is based on an allowable temperature change of -40°F to 212°F . All of the system elements which contribute to these position errors are contained within the Electronic Controller Assembly.

In addition to those factors shown on Figure 13, which contribute to steady state position errors, one additional consideration is significant. Non-ideal integration in the integrating D.C. amplifier introduces position errors which are proportional to the actual sphere position relative to the position of electrical zero. This error is equal to the sphere position (from electrical zero) divided by 187 (the open loop gain). This error becomes a maximum of 0.13 degrees for positions of -10° degrees in α and 0.11 degrees for positions of ± 20 degrees in β .

4.5 Frequency Response Characteristics

4.5.1 α or β Outer ΔP Servo Loop:

The frequency response data shown on Figure 14 were obtained experimentally from wind tunnel tests; see Section 4 of the Summary Test Report, with a tunnel dynamic pressure of 35 p.s.f., an input amplitude motion of $\pm 4.0^{\circ}$, and an outer open loop gain of 234 deg/deg



SENSOR STATIC ACCURACY

FIGURE 13

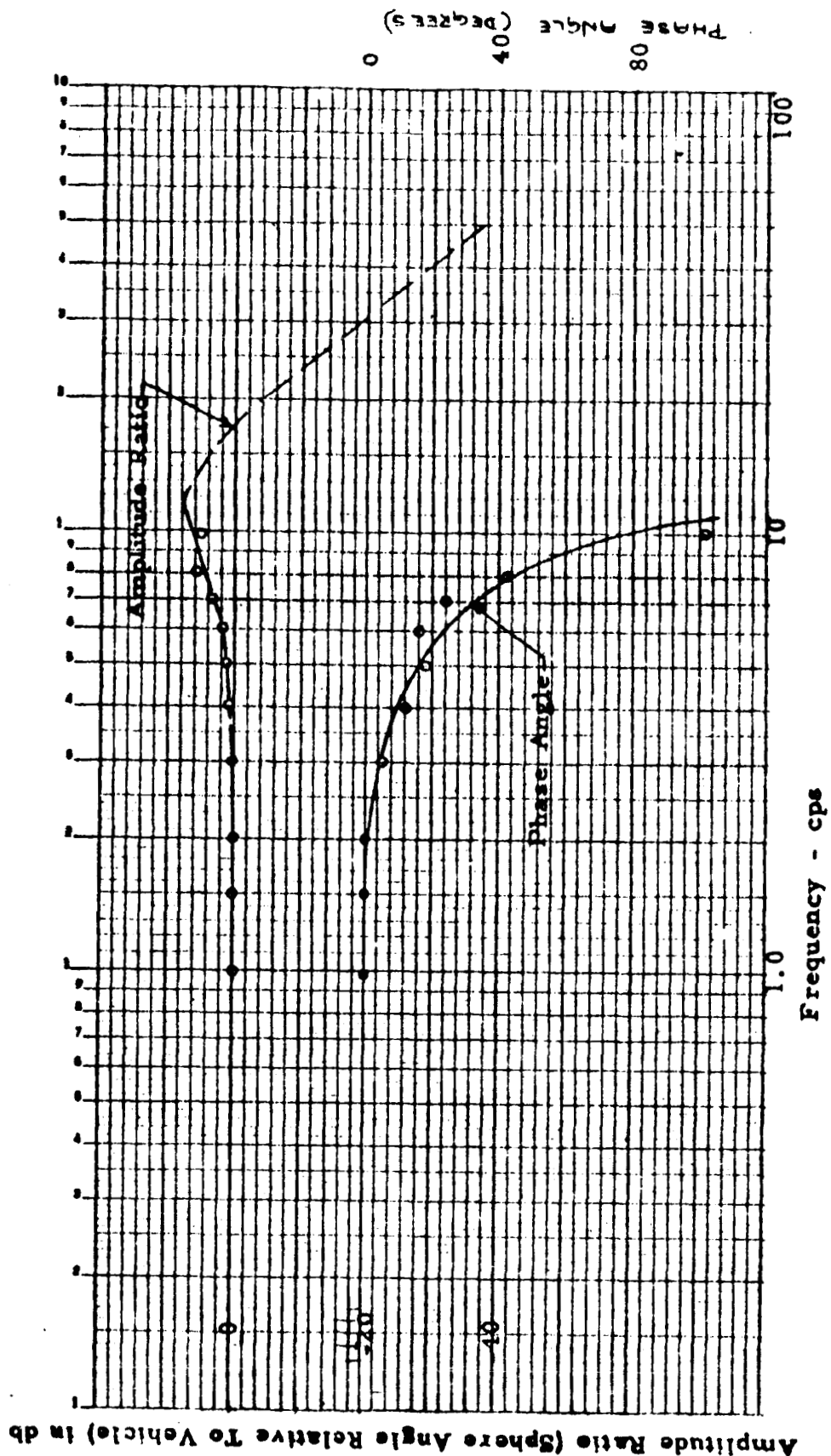


Figure 14 NASA SENSOR CLOSED OUTER LOOP FREQUENCY RESPONSE



(corresponds to 50 $\frac{\text{deg}}{\text{sec}}$ for ideal integration in the outer loop integrator). The outer open loop gain was reduced to the present level of 40 $\frac{\text{deg}}{\text{sec}}$ subsequent to these tests.

The following factors affect the accuracy of the outer open loop gain and consequently the frequency response:

1. Accuracy of the gain compensating ΔP transducer, within the range of gain compensation, may result in gain variation of up to ± 2.0 db. This gain error is maximum at $q = 15$ p.s.f. and is primarily related to null shift of the ΔP gain changing transducer with temperature.
2. The gain changing servo is mechanized with an assumed pressure difference between the total pressure orifice and the β orifice of $0.8 q$ (Figure 2 of N.A.C.A. TN 3344 for $M = 3.80$). Variations in this pressure difference due to Mach number or other effects on the pressure distribution over the sphere will produce inversely proportional changes in the gain setting commanded by the gain compensating servo.
3. Electrical loading of the α or β gain changing potentiometers results in a maximum gain error of -1.2 db at a dynamic pressure of 30 p.s.f.
4. The outer open loop gain is unaffected by supply voltage variation (see Section II-3 of Summary Test Report NORT 59-142).
5. The outer loop nominal gain, 187 deg/deg , is based on an assumed sphere orifice sensitivity of:



$$\frac{\Delta P}{Q} = .059 q \text{ psf/deg} \quad (\text{Figure 2 of N.A.C.A. TN 3344 for } M = 3.80)$$

ΔP is the differential pressure seen between a pair of sensing orifices, each located 42 degrees from the stagnation point, θ is the unit angular displacement of the sphere reference axis with respect to the wind vector, and q is the free stream dynamic pressure. Any change in the sphere orifice sensitivity due to Mach number or other effects will produce directly proportionate outer loop gain variation. This gain variation tends to be offset by the opposite effect stated in item 2. above.

6. Outside the range of gain compensation, the outer loop gain varies directly with the ratio of the actual dynamic pressure divided by the compensation limit, i.e., $q/15$ for operation with dynamic pressure below the compensation range and $q/2500$ for operation above the compensation range.

4.5.2 α or β Positional Servo Loop:

The frequency response shown on Figure 15 was obtained from experimental tests and shows the dynamic characteristics of the α or β positional servos with a nominal open loop gain setting of $17 \frac{\text{deg/sec}}{\text{deg}}$.

Particular attention should be made to the data plotted on Figure 15 which shows the coupling effects of the N.A.S.A. LDZ 32487 self-synchronous recorder on the dynamic behavior of these servos. This

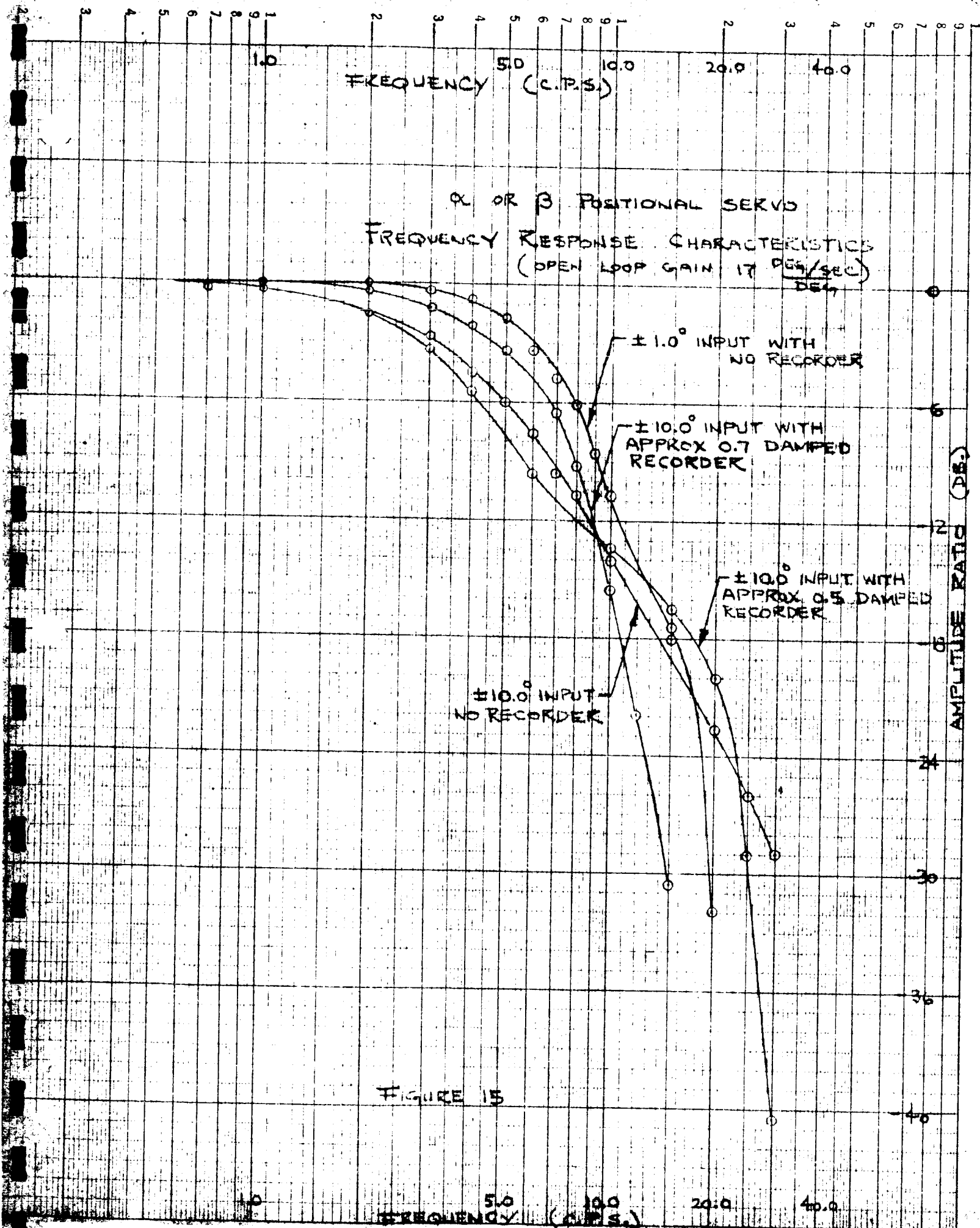


FIGURE 15



condition arises because the voltage across the stator windings S_1 and S_3 of the Sensor α and β synchro transmitters is used for the feedback signal in these servos. Therefore, any extraneous voltage appearing across these stator windings which is generated by the recorder synchro will be reflected in the positional servo response.

Figure 15 shows that the Sensor servo response is particularly sensitive to the damping adjustment of the receiver synchro. Also, the natural coupling frequency of the transmitter and receiver synchro appears about 14 c.p.s. Reference to Figure 14 shows that the outer α and β AP control loops are especially sensitive to oscillatory disturbances around this synchro coupling frequency.

From the above considerations, the optimum receiver synchro damping ratio adjustment appears to be approximately 0.7.

4.6 Sensor α and β Servo Velocity Characteristics

4.6.1 α and β Positional Servo:

Velocity limitation of the α or β positional servo is determined entirely by the flow characteristics of the hydraulic servo valve. The output saturation level of the current feedback D.C. valve amplifier is $\pm 9^6$ ma., while the servo valve is rated for a maximum flow of 0.385 in³/sec at ± 4.0 ma. input. This maximum rated flow is equivalent to a no-load actuator angular velocity of ± 236 degrees/sec. This rated flow is specified for supply fluid at 3000 p.s.i. and 100°F. Temperature variation of the supply fluid will



produce variations in the maximum flow capacity of the valve due to the change of the fluid viscosity with temperature. The magnitude of the resulting variation in the servo maximum velocity is approximately as follows:

With supply fluid at -40°F : 120 deg/sec

With supply fluid at 250°F : 300 deg/sec

4.6.2 α and β Outer ΔP Servo:

For Sensor operation with dynamic pressures below 1050 p.s.f., the maximum outer loop sphere velocity is limited to 88 deg/sec due to the voltage saturation of the outer loop demodulator.

For Sensor operation with dynamic pressure above 1050 p.s.f., the velocity output of the outer loop is limited by the saturation of ΔP error transducer. The resulting maximum velocity capability above 1050 p.s.f. is equal to $\frac{1050 \times 88}{q_{\text{actual}}}$ deg/sec..

q_{actual}

The above relationships may be seen by the following analysis:

With an outer loop demodulator output saturation level of ± 14 V.D.C. and with an error voltage level of 6.45 V/deg at this point, the demodulator will saturate with a sphere position error relative to the wind vector of $14/6.45$ or 2.2 degrees. With an open loop gain of 40 $\frac{\text{deg}}{\text{deg/sec}}$ the resulting maximum velocity command by the outer loop is 88 deg/sec.



With a sphere orifice sensitivity of .059 q p.s.f./deg and with a ΔP transducer saturation of 135 p.s.f., a 2.2 degree error is below the saturation level of the transducer for operation with dynamic pressure below:

$$q = \frac{135}{.059 \times 2.2} = 1050 \text{ p.s.f.}$$

4.7 Threshold of the α or β Servo System

The control threshold of the α or β outer ΔP servo is determined entirely by the threshold of the combined hydraulic servo valve and actuator. The threshold of this combination is in turn determined by the pressure gain of the valve and the breakout static friction of the actuator.

Test measurements have demonstrated the ability of the α or β servo systems to respond with fair fidelity to a sinusoidal voltage command of 0.5 c.p.s. with a peak-to-peak sphere motion of 0.04 degrees.

Properly filtered hydraulic fluid initially cleaned to 2 microns and maintained to 10 microns is essential to the realization of this threshold capability.

Also contributing to the low threshold capability of the system is a small 400 cycle/sec noise component superimposed on the voltage output of the outer loop integrating amplifier. This noise adds an effective dither signal to the servo valve approximately equal to a



200 μ a peak-to-peak valve current. System threshold capability should therefore be demonstrated with the output of the integrating amplifier ungrounded.

4.8 Backlash of the α or β Servo Systems

Backlash in the α or β sphere actuation systems is limited to the geared coupling between the actuator pistons and actuator shafts. Diametrically opposed and cross ported actuator pistons each with a small differential area provide inherent hydraulic preloading to these gear teeth. The preload is equivalent to an external sphere torque of 69 in-lb. Below the level of this preload, zero backlash is obtained. The preloading arrangement may be seen by reference to Figure 10A.

4.9 Inflight Test System

4.9.1 Nominal Sphere Position in Response to the Test Command:

Angle of Attack, α : -5 deg

Angle of Sideslip, β : + 15 deg Positive β is defined with the front of the sphere displaced right looking forward.

4.9.2 Sphere Positional Accuracy in Response to the Test Command:

Angle of Attack, α : ± 5 deg (RMS of total error)

Angle of Sideslip, β : ± 5 deg (RMS of total error)

An analysis of possible error sources in the sphere commanded position is presented below:



1. The zener point of the zener diode used to regulate the D.C. voltage command may vary $\pm 5\%$. This tolerance corresponds to sphere displacements of ± 1.03 deg in α and 0.79 deg in β .
2. The α or β synchro transmitter output sensitivity may vary $\pm 9\%$ due to A.C. supply voltage variation. This variation corresponds to sphere displacements of ± 1.8 deg in α and ± 1.4 deg in β about the nominal commanded position.
3. The null of the hydraulic servo valve may shift $\pm 10\%$ of maximum rated flow due to temperature changes from -40°F to 400°F . This null shift corresponds to ± 1.5 deg of sphere displacement in both α and β .
4. The tolerance in the null alignment of the α or β synchro transmitters is ± 1.0 deg.
5. Temperature drift of the output of the D.C. valve amplifier may be ± 2 volts. This drift corresponds to ± 3.8 deg of sphere displacement in both α or β .

It should be noted that a combined error of ± 5 deg in the positional servo loop is essentially canceled during normal sensor operation by the high gain of the outer loop. The resulting outer loop error may be obtained by dividing the position loop error, ± 5 deg, by the outer loop gain, 187, or $\pm .027$ deg.



4.9.3 Sphere Recovery Characteristic

During the time interval of the test command, interruption of the normal function of the outer servo loop will produce the following conditions:

1. The α and β outer loop integrating amplifiers will saturate due to the large steady state ΔP existing between both pairs of sensing orifices during the test interval.
2. The outer loop gain changing servo will drive the outer loop gain to a level which corresponds to the actual ΔP between the pitot orifice and the β right orifice during the test interval.

The β polarity of the test command, i.e., front of sphere moves right, is chosen such that the change in the outer loop gain is minimized during the test interval. Reference to Figure 2 of N.A.C.A. TN 3344 shows that a steady state β right error of 15 degrees increases the ΔP between the pitot orifice and the β right orifice, and, consequently, reduces the servo gain setting by only 3 db. Upon release of the test command the effect of this small transient gain error will be indiscernible on the normal sphere response characteristics. The recovery time to the proper gain setting is determined by the velocity capability of the gain changing servo (see Section 4.10). The time required is also a function of the dynamic pressure. Table 1 below shows approximate time to recovery.



overpressure due to the commanded misalignment of the sphere and sensing ports with respect to the wind vector. Reference to Figure 2 of N.A.C.A. TN 3344 shows that this differential overpressure may reach a maximum of $2.0 q$ across the α or β ports.

The α and β differential pressure transducers are rated at 108 p.s.f. (0.75 p.s.i.) full scale. However overpressure to 20 times this rating is permissible without a significant shift in the null of the instrument.

Because of the above considerations, operation of the inflight test should not be performed during flight when the dynamic pressure exceeds 1000 p.s.f.

4.10 Gain Changing Servo Characteristics

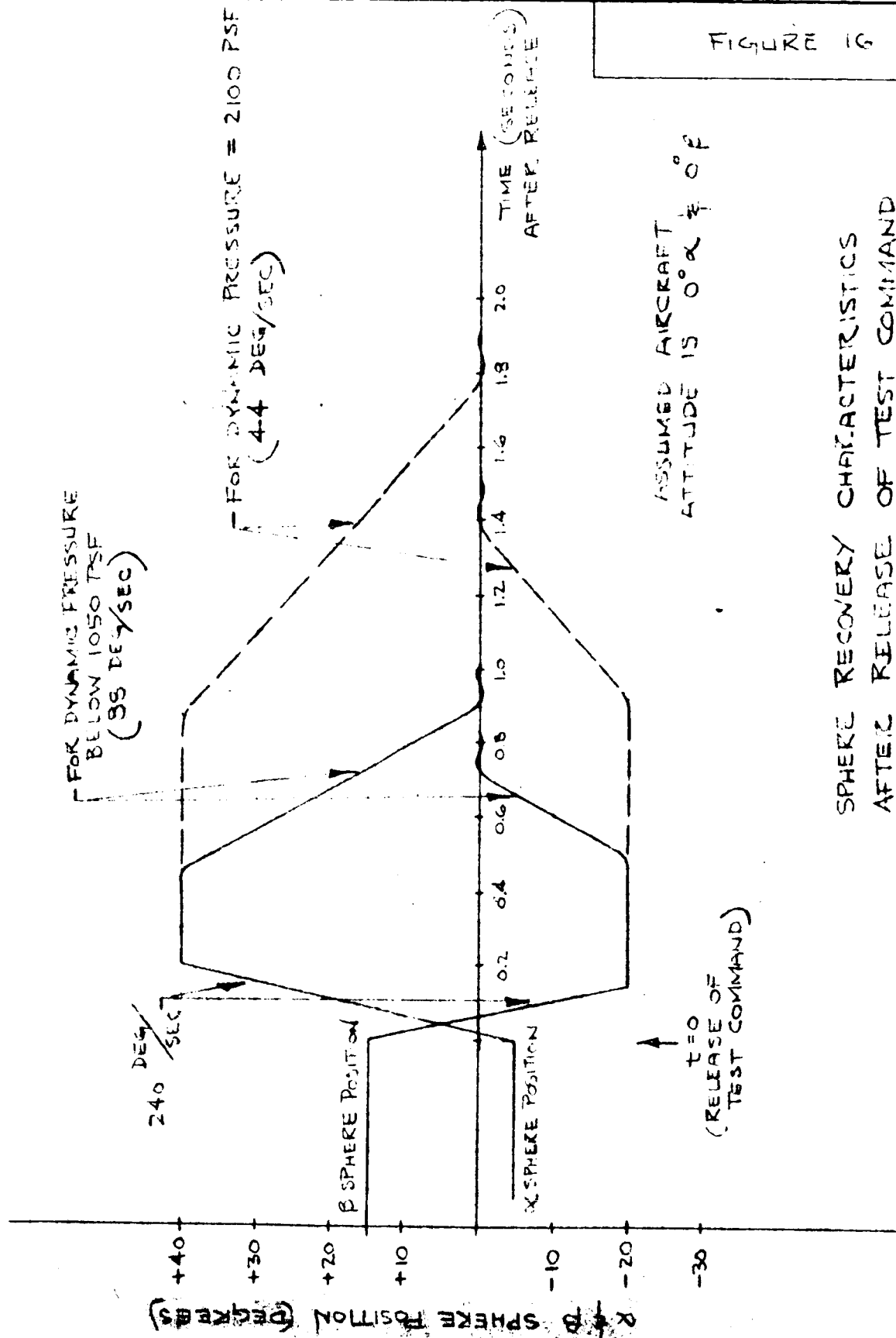
A detailed mechanization diagram of the gain changing servo is given on Figure 17. An analysis of this system will show the following servo characteristics:

4.10.1 Tracking Error

The loop is a type I servo and will exhibit a constant position error in tracking. This error expressed in terms of the dynamic pressure of the airstream is given by:

$$q_{\text{error}} = \frac{1}{.0264} q_{\text{actual}} \quad \frac{\text{psf}}{\text{psf/sec}}$$

ENGINEER	NORTHROP AIRCRAFT, INC. NORTHROP DIVISION	PAGE 42
CHECKER		REPORT NO. NORT 60-46
DATE 1-26-60		MODEL





Gain Recovery Time Seconds	Dynamic Pressure P.S.F.
6	15
3	30
1.5	60
0.75	120

Table I

The effect of the saturation of the outer loop integrator on the sphere recovery characteristics is shown in Figure 16. The response shown assumes an aircraft attitude of zero angle of attack and zero sideslip angle. Below dynamic pressures of 1050 p.s.f. the outer loop sphere recovery velocity is limited by the saturation of the outer loop demodulator; above 1050 p.s.f. the maximum recovery velocity is determined by the saturation of the ΔP error transducer (see Section 4.6.2).

Upon release of the test command, the rapid sphere travel to the opposite travel stop positions of + 40 deg in and α -20 deg in β is due to the initial step command to the α and β positional servos caused by the full -15 volt output saturation voltage stored in the outer loop integrators.

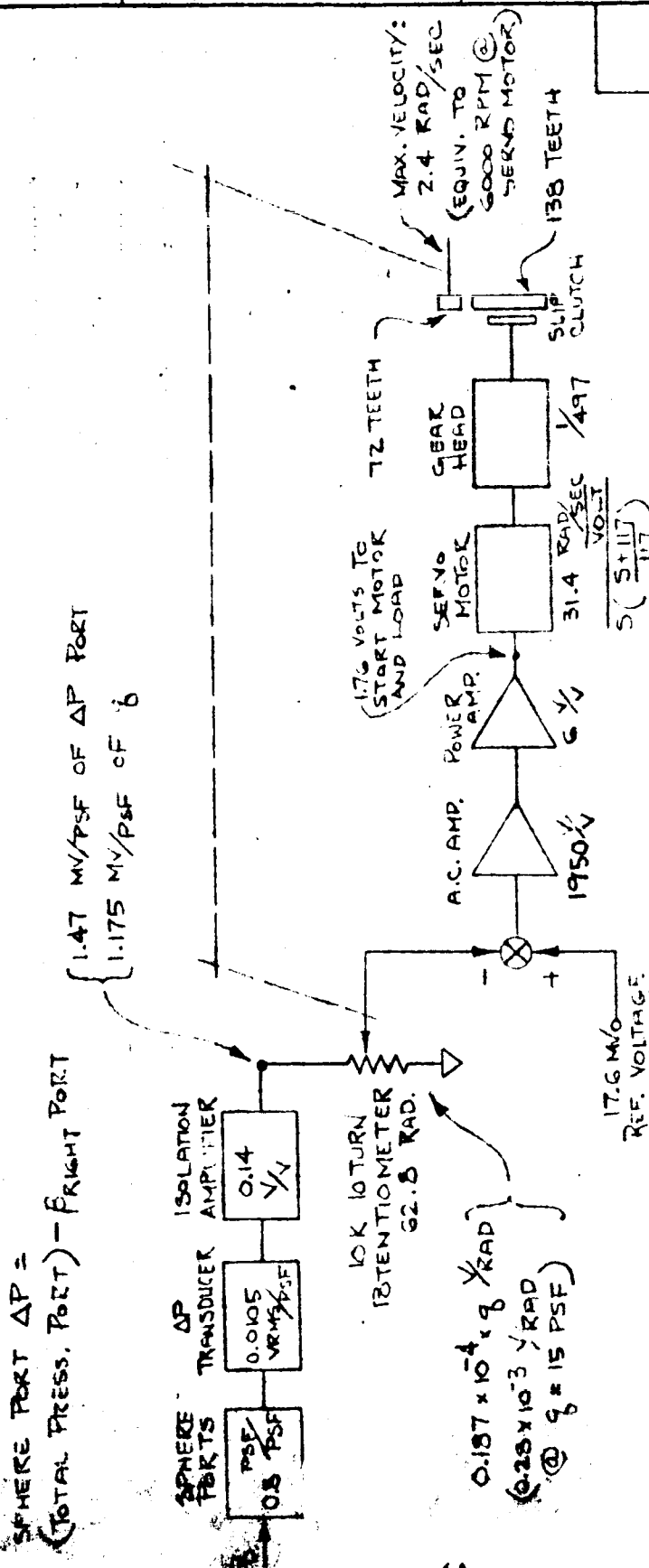
4.9.4 Operational Restrictions

During the operation of the inflight test, the sensitive α and β ΔP error transducers are exposed to large abnormal differential

ENGINEER	NORTHROP AIRCRAFT, INC. NORTHROP DIVISION	PAGE 44
CHECKER		REPORT NO. NORT 60-46
DATE 1-26-60		MODEL

MECHANIZATION DIAGRAM -
GAIN CHANGING SERVO

FIGURE 17



SERVO MOTOR DATA :

MAX. CONTROL VOLTAGE : 40 VRMS
STALL TORQUE : 0.25 IN-OZ
MAX SPEED (NO LOAD) : 6000 RPM

SERVO OPEN LOOP GAIN

$$= 0.0264 \frac{\text{RAD/SEC}}{\text{RAD}} \left(\delta = 15 \text{ IN P.S.F.} \right)$$

$$= 0.396 \frac{\text{RAD/SEC}}{\text{RAD}} \left| \delta = 15 \text{ PSF} \right.$$

$$= 66 \frac{\text{RAD/SEC}}{\text{RAD}} \left| \delta = 2500 \text{ PSF.} \right.$$



The above expression gives the q_{error} in the automatic positioning of the servo during a steady state rate of pressure change of 1 psf/sec with an instantaneous dynamic pressure of q_{actual} p.s.f. For the extremes of the dynamic pressure range, 15 to 2500 p.s.f., this tracking error will be:

$$q_{\text{error}} = 2.52 \frac{\text{psf}}{\text{psf/sec}} \quad | q = 15 \text{ psf}$$

and

$$q_{\text{error}} = .0152 \frac{\text{psf}}{\text{psf/sec}} \quad | q = 2500 \text{ psf}$$

4.10.2 Velocity Capability

The velocity of the servo is limited by the maximum output velocity of the servo motor, 2.4 rad/sec at the potentiometer shaft, and is given by the following expression in terms of the dynamic pressure:

$$\frac{dq}{dt}_{\text{max}} = \frac{2.4}{10 \times 2\pi \times 15} (q_{\text{actual}})^2$$

Where q_{actual} is expressed in p.s.f.

At the extremes of the range of dynamic pressure the maximum servo velocities are given below:

$$\frac{dq}{dt}_{\text{max}} = .57 \text{ p.s.f./sec} \quad | q = 15$$

and

$$\frac{dq}{dt}_{\text{max}} = 2.38 \times 10^5 \text{ p.s.f./sec} \quad | q = 2500$$



The time required for the servo to travel from one potentiometer travel stop to the other may be obtained by dividing the total potentiometer travel, 52.8 radians, by the maximum potentiometer shaft velocity, 2.4 rad/sec, or 26 seconds.

4.10.3 Threshold

The threshold of the servo is determined by the starting voltage required by the servo motor and its load. This voltage at the motor control field is 1.76 volts or expressed in terms of the dynamic pressure is:

$$q_{\text{threshold}} = .178 \frac{(q_{\text{actual}})}{15}$$

Where q is expressed in p.s.f. Thus, the servo threshold becomes approximately 1.0% of the actual ΔP seen between the pitot port and the right β port.

4.10.4 Servo Dynamics

The dynamic stability characteristics of the closed loop are determined by the open loop gain. This gain is related to the dynamic pressure by the following expression:

$$\text{Open Loop Gain} = .0264 q \frac{\text{rad/sec}}{\text{rad}}$$

where q is expressed in p.s.f.



The closed loop dynamic response, therefore, is a function of the dynamic pressure.

For the extremes of the dynamic pressure range, the dynamics of the closed loop servo are given by the following transfer functions:

$$\frac{\theta}{R} = \frac{K}{\frac{(s + 117)}{117} \frac{(s + .39)}{.39}} \quad |q = 15$$

and

$$\frac{\theta}{R} = \frac{K}{\left(\frac{s^2}{882} + \frac{2 \times .65}{88} s + 1\right)} \quad |q = 2500$$

4.11 Sensor Thermal Characteristics

4.11.1 Operating Temperature Range

The Sensor is designed to sufficiently cool the internal equipment with the outer Inconel-X Sensor surfaces stabilized at 1200°F for an indefinite period. The total LN₂ required under these conditions is 0.98 lb/min (see Section 7 of the Summary Test Report, NORT 59-142).

The maximum allowable internal equipment operating temperatures are as follows:

Electronic Controller Assembly:

Internal: 212°F

External: 180°F

Sphere Actuation Assembly: 400°F

The minimum sensor operating temperature is -40°F.



4.11.2 Sphere Cooling System Characteristics

The circuit and relay which control the sphere LN₂ valve are designed to open the valve when the sphere sensing thermistor temperature rises to 112°F. Variations of ± 4 V.D.C. in the 28 V.D.C. supply and variations of $\begin{matrix} +212 \\ -65 \end{matrix}$ °F in the internal temperature of the Electronic Controller reflect a ± 6 °F variation in this sphere LN₂ valve operating set point. The valve closes when the sphere sensing thermistor temperature drops 6 ± 4 °F below the operating point.

The sphere LN₂ valve is spring loaded closed and opens when electrically energized. The valve solenoid is rated at room temperature and 28 V.D.C. for 1.25 amperes maximum current.

4.11.3 Cone Cooling System Characteristics

The circuit and relay which control the cone LN₂ valve are designed to open the valve when the cone sensing thermistor temperature rises to 117°F. Variations in the D.C. supply voltage and variations in the internal temperature of the Electronic Controller reflect a ± 10 °F variation in this operating set point. The valve closes when the cone sensing thermistor temperature drops 6 ± 4 °F below the operating point.

The cone LN₂ valve is identical to the sphere LN₂ valve.



4.11.4 Blowdown Operating Characteristics

The nominal operating set points of the blowdown thermostwitch are:

Switch closes: + 15°F

Switch opens: - 15°F

5. Special Assembly Instructions

The following information is included to provide a summary of the adjustment procedures required during the normal assembly of the Sensor. Adjustments or service of Sensor commercial components should not be attempted; these should be returned to the manufacturer for any repair needed.

5.1 Polarity and Null Alignment of the β Synchro Transmitter (Reference Drawing 5212143)

Cement the stator of the β synchro using Plastilock #605 (B. F. Goodrich Co.) to the β Actuator Yoke P/N 5212144 in a position such that the stator lead wires emerge approximately as shown in Figure 18.

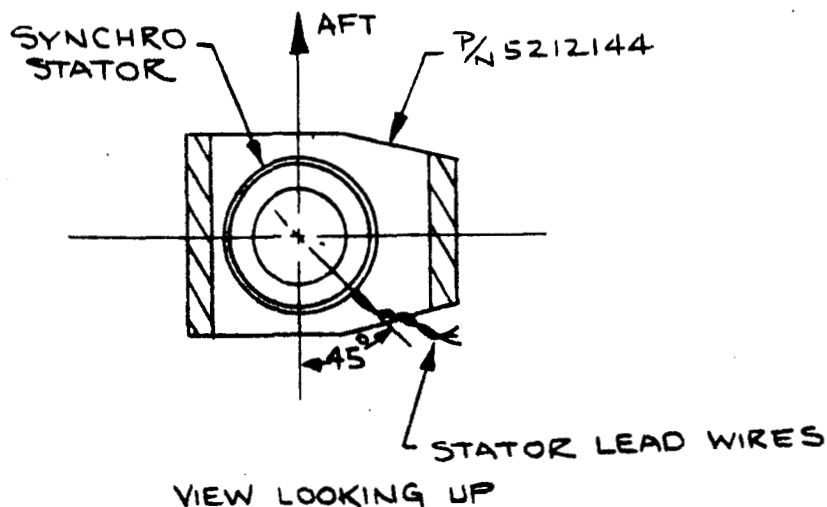


FIGURE 18

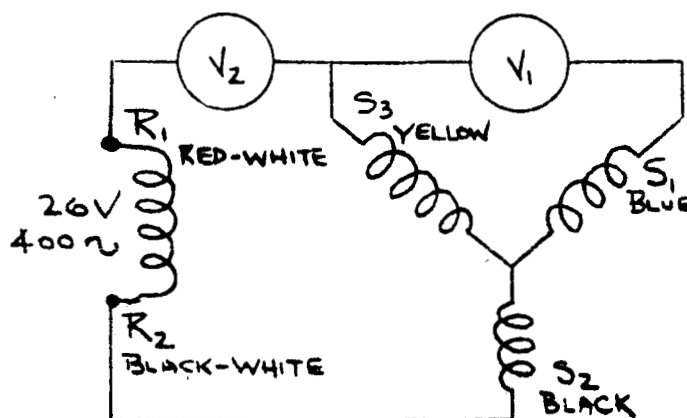


Assemble the β Synchro Shaft P/N 5212152, the β Synchro Stub Shaft P/N 4212145, and the β Actuator Shaft P/N 4212146 with their support bearings to the β Actuator Yoke. Insert the alignment pin between the β Synchro Stub Shaft and the β Synchro Shaft. Install the assembled β yoke in the Sphere Assembly P/N 5212132 and assemble the Sphere Cap P/N 5212132-11 and retaining ring P/N 5102-250W. Place the synchro rotor on the Synchro Stub Shaft such that the rotor leads are brought out toward the interior of the β yoke. Lightly secure the rotor to the shaft with a #6-32 machine screw.

Mount the Sphere Assembly on a suitable holding fixture and adjust the sphere such that the two β orifices are equidistant from a flat horizontal reference surface. Rotate and clamp the β yoke such that a height gage indicates the aft ground face of the β yoke to be laterally parallel to the flat horizontal reference surface.

The β position of the β yoke is now at mechanical zero with respect to the sphere β orifices.

A schematic of the synchro connected for electrical polarity and null alignment is shown in Figure 19.



ADJUST SYNCHRO ROTOR FOR V_1 NULL VOLTAGE OF 30 MV OR LESS.

V_1 & V_2 ARE BALLENTINE #315 OR EQUIVALENT VOLTMETERS.

V_2 READS 17 VRMS AT CORRECT NULL ; 40 VRMS AT NULL 180 DEGREES AWAY FROM CORRECT NULL.

FIGURE 19

-50-

NORT 60-46



With the rotor excited with a 26V, 400 cycle/sec source and with the synchro connected as shown in Figure 19, rotate the rotor on the β stub shaft to a position such that V_1 reads approximately a null and V_2 reads approximately 17 VRMS. This is the correct null of the synchro. If V_1 reads a null but V_2 reads 40 VRMS, rotate the synchro rotor 180° on the β stub shaft.*

With the correct null located, disconnect V_2 and adjust the rotor about the correct null until a voltage of 30 MV or less is read on V_1 . Lock the rotor to the shaft by tightening the #6-32 machine screw.

With the synchro rotor secured remove the β stub shaft from the β yoke and drill and install the 047-025-MCK Spirol pin between the shaft and the synchro rotor.

Reassemble the β stub shaft in the β yoke. The synchro null must measure within 1.0 degrees of β mechanical zero.

The resulting polarity gives S_1 with respect to S_3 in phase with R_1 for $-\beta$, i.e., front of the sphere displaced left looking forward.

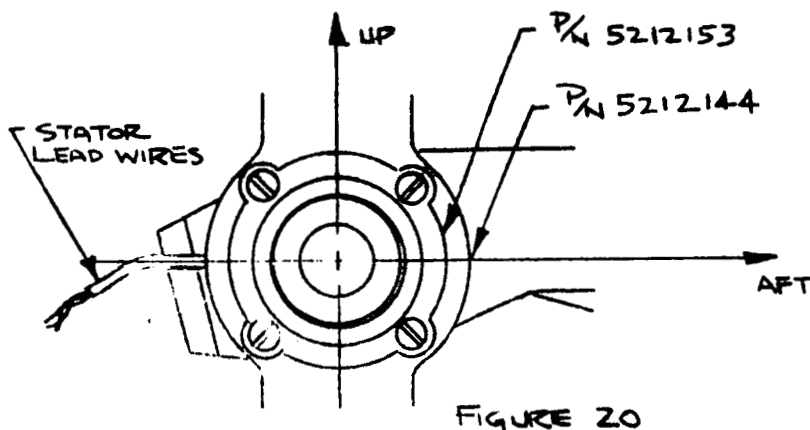
* The correct null may also be stated by defining S_1 and S_3 in phase with R_1 .



With the β transmitter connected to a proper receiver, and with R_1 of both rotors excited with like phase, the polarity is as stated in Section 4.2.

5.2 Polarity and Null Alignment of the α Synchro Transmitter
(Reference Drawing 5212143):

Cement the stator of the α synchro using Plastilock #605 (B. F. Goodrich Co.) to the α Synchro Housing P/N 5212153 such that the stator lead wires pass through the .09 diameter hole provided. Assemble the α Actuator Shaft P/N 4212137, the α Synchro Rotor Shaft P/N 4212218, the β Actuator Yoke P/N 5212144, and the Synchro Housing P/N 5212153 to the α Actuator Housing Assembly P/N 4214958. Assemble the α Synchro Housing such that the Synchro Stator lead wires emerge as shown in Figure 20.



Install the α Synchro Rotor to the α Synchro Rotor shaft as shown on drawing 5212143 and bring the rotor lead wires to the outside by slipping them through the string tie on the rotor. Lightly



secure the rotor to the rotor shaft with a #6-32 machine screw.

Mount the α Actuator Housing vertically to a flat horizontal surface and rotate and clamp the α Actuator Shaft and β yoke to a position of $+ 15^\circ$ in α , i.e., with the front of the β yoke displaced down. The α Actuator Shaft is now at a position of $+ 15^\circ$ with respect to the α Actuator Housing

Locate and null the electrical zero of the α synchro identical to the procedure used for the β synchro, Section 5.1. Lock the synchro rotor to the shaft with the #6-32 machine screw.

Drill and install the 047-025-MCK Spirol pin between the shaft and the synchro rotor. The final check of the synchro null must measure mechanically within 1.0 degrees of $+ 15^\circ$ in α .

The resulting polarity gives S_1 with respect to S_3 in phase with R_1 for $- \alpha$, i.e., front of the sphere displaced up.

With the α transmitter connected to a proper receiver, and with R_1 of both rotors excited with like phase, the polarity is as stated in Section 4.2.

5.3 Assembly Adjustments of the Gain Changing Servo Assembly (Reference Drawing 4212179)

5.3.1 Slip Clutch Adjustment

Assemble the gear head to the servo motor and attach the gear and slip clutch assembly to the gear head output shaft. Connect the servo motor test circuitry as shown in Figure 21.

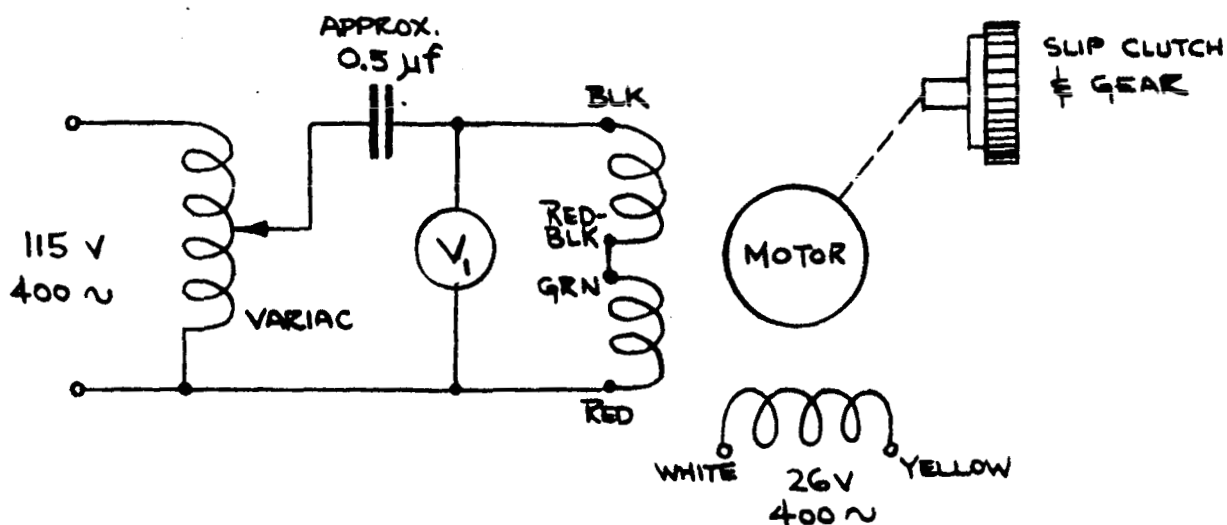


FIGURE 21

With 26 V A.C. applied to the fixed field of the motor, apply a variable voltage at 90° phase lead to the control field. Hold the gear firmly such that it does not rotate with respect to the motor housing. Gradually increase the control field voltage until the clutch just slips, i.e., until the motor just breaks out of stall. The slip clutch should be adjusted until a control field voltage, V_1 on Figure 21, between 10 and 15 V A.C. is required to initiate slippage. Reverse the leads to the fixed field to reverse the direction of motor rotation and retest.



5.3.2 Potentiometer Alignment

A gain setting equivalent to a dynamic pressure of 1250 p.s.f. (potentiometer voltage ratio of 0.12/10.00) is chosen as the set point for the potentiometer alignment.

Install the drive gears on the potentiometer shafts. Before installing the potentiometers in the gain changing Servo Housing and using the test circuit shown in Figure 22, align each of the four potentiometer shafts to a voltage ratio (VR) of 0.12/10.00. The terminal closest to the shaft (CW) is considered as ground or 0.00/10.00 VR and the terminal opposite (CCW) is considered as 10.00/10.00 VR.

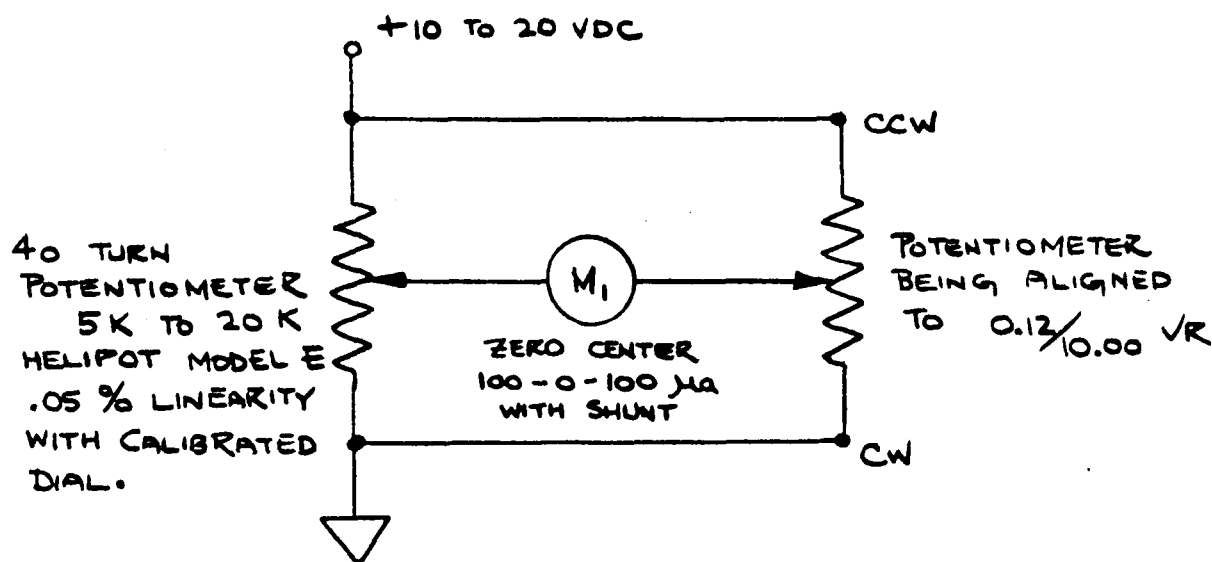


FIGURE 22



Install the servo motor and gear head to the frame using the four hold down screws and clamps. Install one potentiometer at a time with the potentiometer terminals located approximately as shown on Figure 23.

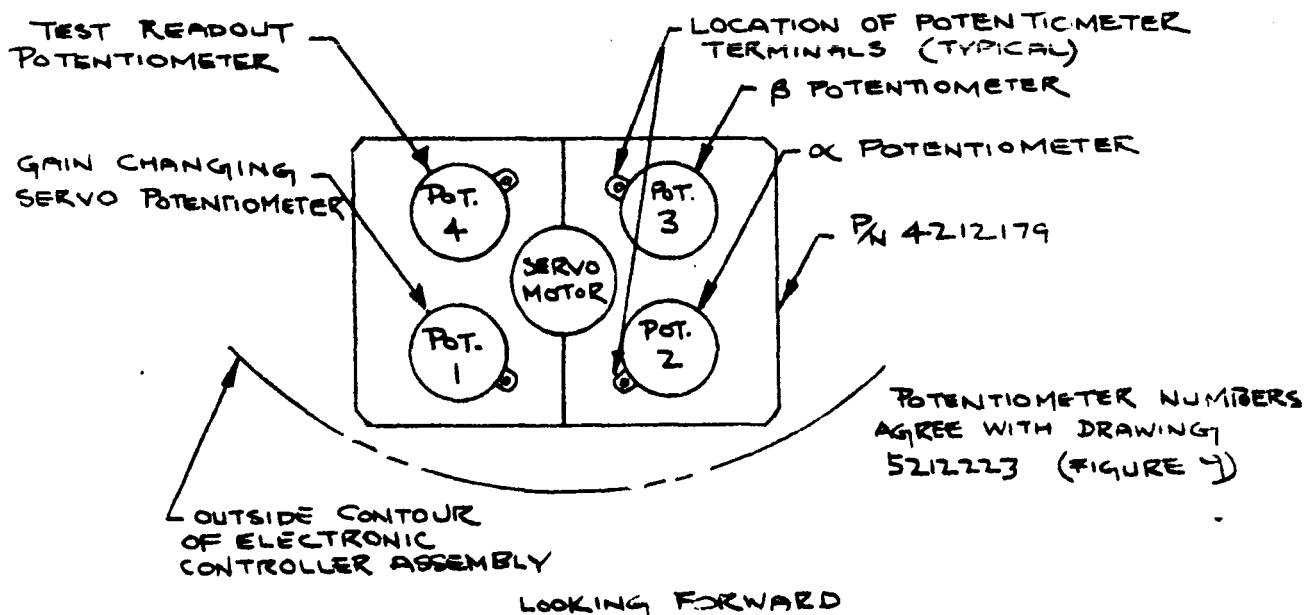


FIGURE 23

As each potentiometer pinion is meshed with the servo motor drive gear, the initial potentiometer setting of 0.12/10.00 VR should be disturbed as little as possible. With all four potentiometers installed and lightly secured with the hold down screws and clamps, slightly loosen one potentiometer at a time and rotate the potentiometer housing until its setting is exactly 0.12/10.00 VR. Repeat this procedure until all potentiometers simultaneously read exactly 0.12/10.00 VR. Safety wire all hold down screws.



5.4 Electronic Circuit Balance Adjustments

The following electrical balance adjustments are made during the initial wiring and assembly of the Sensor. Allow a 15 minute normal warmup of the circuit prior to making the adjustment.

5.4.1 α and β Circuit Board Balance Adjustments - (Reference Drawings 5212170 and 4212175)

1. Potentiometer R4: This potentiometer adjusts the D.C. operating level of the A.C. amplifier. With the amplifier input grounded, terminal 1 on the α - β boards, adjust the potentiometer, R4, until a zero D.C. voltage is measured at the amplifier output test point, terminal 3 on the α - β boards.
2. Potentiometer R21: This potentiometer adjusts the null balance of the D.C. integrating amplifier. With the input test point of the outer loop demodulator grounded, terminal 20 on the α - β boards, adjust potentiometer, R21, until zero D.C. voltage is measured at the output test point of the integrator, terminal 7 on the α - β boards. Allow sufficient time for the long duration transient of the amplifier to settle out.
3. Potentiometer R48: This potentiometer adjusts the null balance of the servo valve D.C. amplifier. With both the amplifier input test point and the integrator output test point grounded, terminals 7 and 10 on the α - β boards,



adjust potentiometer R48 until zero D.C. voltage is measured at the valve amplifier output test point, terminal 11, on the α - β boards. The valve torque motor must be connected to the amplifier output during this adjustment.

4. Capacitor C9: This trimmer capacitor serves as the final fine capacitance balance for the α and β ΔP transducer bridge circuits. With the Sensor completely assembled, it is accessible through the aft cover of the Electronic Controller Assembly (see Figure 1). With zero differential pressure across either the α or β ΔP transducer and with the gain changing servo adjusted to a setting equivalent to a dynamic pressure of 15 p.s.f., adjust the trimmer capacitor C9 until a zero A.C. voltage is measured at the output of the A.C. amplifier, terminal 3 on the α - β boards.

This adjustment should be used only to balance the portion of the servo loop stated above and not to compensate for offset in the D.C. downstream components of the loop.

5.4.2 g Compensation Circuit Board Balance Adjustments (Reference Drawings 5212207 and 5212197)



1. Potentiometer R108: This potentiometer adjusts the D.C. operating level of the gain changing servo A.C. amplifier. With the amplifier input grounded, terminal 15 on the q compensator board, and with the wiper of potentiometer R129 grounded, adjust potentiometer R108 until a zero D.C. voltage is measured at the amplifier output, i.e., at the collector of the Q56 output transistor.
2. Potentiometer R129: This potentiometer adjusts the reference input voltage to the gain changing servo. A gain setting equivalent to a dynamic pressure of 1250 p.s.f. is chosen as the set point for this adjustment. This set point corresponds to a gain changing servo potentiometer voltage ratio of 0.12/10.00 (see Section 5.3.2 for the definition of 0.12/10.00 VR).

Connect the gain changing servo readout test potentiometer as shown in the test circuit of Figure 22. Pressurize the gain compensating ΔP transducer to a pressure equivalent to an actual dynamic pressure of 1250 p.s.f. (1000 p.s.f. gage at the Sensor total pressure port). Adjust the reference potentiometer, R129, until the gain changing servo automatically drives the test readout potentiometer to a voltage ratio of 0.12/10.00.

6. Sensor Parts List

The following sensor parts list is included for reference and identification.

6.1 Nortronics Fabricated Parts

<u>Part Dwg. No.</u>	<u>Nomenclature</u>
<u>5212138</u>	Sensor Assembly - NASA Flow-Direction
<u>5212143</u>	Actuation Assembly - Sphere
<u>5212154</u>	Manifold Assembly - Hydraulic
4213797	Housing - Hydraulic Filter
4212161	Fitting - Hydraulic Return
5214958	Housing Assembly - α Actuator
4212134	Cap - α Actuator
4212135	Piston - 6 Tooth α Actuator
4212136	Piston - 5 Tooth α Actuator
4121237	Shaft Assembly - α Actuator
4212139	Plug - α Actuator
4212140	Plate - α Actuator
5212160	Shield Assembly - Radiation
5212144	Yoke Assembly - β Actuator
4212145	Plate - β Actuator
4212146	Shaft - β Actuator
4212147	Piston - 6 Tooth β Actuator

Part Dwg. No.Nomenclature5212143 (cont'd)

4212148

Actuation Assembly - Sphere

4212149

Piston - 5 Tooth β Actuator

4212150

Plug - β Actuator

4212151

Shaft - Stub β Synchro

5212152

Bracket - Servo Valve Electrical Connector

5212153

Shaft - β Synchro

5212155

Housing - α Synchro

5212156

Manifold Assembly - LN₂ Distribution

5212157

Stop Assembly - α and β Actuator

5212158

Mount - α Stop

4212159

Shim Set - β Synchro Shaft and α Actuator
Shaft Bearings

4214959

Spacer Set - β Synchro Shaft Bearings

4212162

Probe Assembly - Sphere Thermistor

4212225

Insulator - LN₂ Line Thermal

4212218

Shield - Wire Abrasion

4212220

Shaft - α Synchro Rotor5212132

Bracket - Radiation Shield Mounting

4213789

Sphere Assembly - NASA Sensor

4213792

Fitting - Angle Orifice Tube End

4213788

Fitting - Pitot Orifice Tube End

4212165

Plate - Orifice Tube

Hose Assembly - Orifice

Part Dwg. No.Nomenclature5212143 (cont'd)

Actuation Assembly - Sphere

4212191

Fitting Assembly - Orifice Hose Aft

4212165-7

Clamp - Pitot Orifice Hose

4212165-9

Clamp - Error Orifice Hose

4212165-11

Ring - Pitot Orifice Hose Clamp

4212165-27

Ring - Error Orifice Hose Clamp

4213798

Cap - Hydraulic Filter

5212171

Controller Assembly - Electronic

4212175Circuit Board Assembly - α and β

5212170

Circuit Schematic - α and β 5212172 (2 sheets) Circuit Board - α and β Fabrication

5212173

Circuit Master - α and β Front (no dwg.)

5212174

Circuit Master - α and β Rear (no dwg.)

5212180

Manifold Assembly - Pneumatic Forward

4214955

Bracket - LN_2 Valve Mounting

5212181

Manifold Assembly - Pneumatic Aft

5212182

Housing Assembly - Electronic Controller

4212186

Adapter - Electronic Controller Electrical Connector

4212185

Gasket - Electronic Controller Electrical Connector

4212179

Servo Assembly - q Compensator

Part Dwg. No.Nomenclature

5212171 (cont'd)	Controller Assembly - Electronic
4212177	Motor Assembly - q Compensator
4212176	Potentiometer Assembly - q Compensator
5212178	Housing Assembly - q Compensator
<u>5212197</u>	Circuit Board Assembly - q Compensator
4212207	Circuit Schematic - q Compensator, Fail Warning, and Temperature Control
4212190 (2 sheets)	Circuit Board - q Compensator Fabrication
5212198	Circuit Master - q Compensator Front (no dwg.)
5212199	Circuit Master - q Compensator Rear (no dwg.)
4212214	Insulator - Circuit Board Electrical
4212222	Shield - Electrostatic
<u>4213793</u> (2 sheets)	Circuit Board Assembly - Fail Warning and Temperature Control
5213923 (2 sheets)	Circuit Board - Fail Warning and Temperature Control Fabrication
5213921	Circuit Master - Fail Warning and Temperature Control Front (no dwg.)
5213922	Circuit Master - Fail Warning and Temperature Control Rear (no dwg.)
4212211	Spacer-Circuit Board (-3, -5, -9, -11, -13)
4213783	Lip Assembly - Cone Front
5212200	Skin Assembly - Cone
4212216	Ring - Aft Bulkhead Seal

Part Dwg. No.Nomenclature

4212217	Gasket - Aft Bulkhead Seal Ring
5212202	Heat Exchanger Assembly - Inner
<u>5212193</u>	Heat Exchanger Assembly - Outer
5212201	Form - Heat Exchanger Tube
4214957-1	Coupling - LN ₂ Inlet, Exchanger Half
5212192	Skin - Outer Heat Exchanger
5212203	Bulkhead Assembly - Rear
4214956	Tube Assembly - Total Pressure
5212196	Insulator Assembly - Rear Bulkhead
5212194	Clamp - Cone Temperature Probe
4212205	Bracket - Cone Electrical Connector
4212210	Gasket - Total Pressure Tube
4212213	Insulator Assembly - Hydraulic Manifold Thermal
4214950	Filter Assembly - LN ₂
<u>4213919</u>	Probe Assembly - Cone Temperature
. 4213920	Probe Assembly - Cone Thermistor
4213918	Housing - Cone Temperature Probe
4214951	Plate - Sphere Electrical Connector Clamp
4214953	Bracket - Sphere Electrical Connector Mounting
4214952	Spacer - Sphere Electrical Connector
4214957-3	Tube Ass'y-Cone LN ₂ Inlet
4214960	Bracket - Blowdown Switch Mounting

Part Dwg. No.Nomenclature

4214954	Pin-Pitot 3/8 Tube Coupling
5212188	Insulation - Cone
4212219	Pin - LN ₂ Coupling Alignment
4213781	Ring - Sphere Seal
4213785	Spring - Sphere Seal
4213784	Cable Assembly - Sensor Electrical
5212223	Schematic - Sensor Wiring
5213924	External Configuration - NASA Flow-Direction Sensor
02580001	Sensor System Analyzer
02580003	Electronic Module Test Unit
02580004	Sensor Electrical Calibration Unit

6.2 Sensor Commercial Parts6.2.1 Electronic Controller Assembly (Nortronics P/N 5212171):

<u>Part Nomenclature</u>	<u>Parts/Sensor</u>	<u>Vendor P/N</u>	<u>Vendor</u>
α or β ΔP Transducer	2	Type 2442	Trans-Sonics, Inc.
q Compensation ΔP Transducer	1	Type 2443	Trans-Sonics, Inc.
Power Transformer (T-51)	1	#E10999	Electro- Eng. Works
ΔP Transducer Excitation Transformer (T-52)	1	#1572	Trans-Sonice, Inc.
Electrical Connector (P1 plug)	1	PT07-P-14-19P	Scintilla Div., Bendix Avn., Inc.
Electrical Connector (P-2 plug)	1	PT07-P-14-19PW	Scintilla Div., Bendix Avn., Inc.

6.2.1 Electronic Controller Assembly (Nortronics P/N 5212171):

<u>Part Nomenclature</u>	<u>Parts/Sensor</u>	<u>Vendor P/N</u>	<u>Vendor</u>
Cover Seal (O-ring)	1	AN6230-37	Std. Part
Pneumatic Seals (O-rings)	5	MS29513-12 COMP-363-70	Parco
LN ₂ Valve	2	11C530 Crocker Mfg. Co.	

6.2.1.1 q Compensation Servo Assembly (Nortronics P/N 4212179):

<u>Part Nomenclature</u>	<u>Parts/Sensor</u>	<u>Vendor P/N</u>	<u>Vendor</u>
Servo Motor	1	8SM420-9	Helipot Div., Beckman Inst. Inc.
Servo Motor Gear Head	1	88375-12-120 Size 8-ET7- 0497	Exact Eng. & Mfg. Co.
Gear and Slip Clutch	1	MSC 650-138/ 125	Dynamic Gear Co.
Pinion	4	656-725	Dynamic Gear Co.
Potentiometer	4	500-716	Spectrol

6.2.1.2 q Compensation Circuit Board Assembly (Nortronics P/N 5212197):

<u>Part Nomenclature</u>	<u>Parts/Sensor</u>	<u>Vendor P/N</u>	<u>Vendor</u>
Tube Shield ()	1	T-3 421L	Birtcher
Relay (Cone or Sphere LN ₂ Valve)	2	3S2791G 200-S -9	General Electric
Transformer (T-53)	1	DOT-20	United Transformer Co.
Choke (EC-250)	2	TO 26764	Triad
Transistor (Q-57, Q-58)	2	2N498	Texas Inst.
Transistor (Q-56)	1	2N343	Texas Inst.

6.2.1.2 q Compensation Circuit Board Assembly (Nortronics P/N 5212197):

(Cont'd)

<u>Part Nomenclature</u>	<u>Parts/Sensor</u>	<u>Vendor P/N</u>	<u>Vendor</u>
Transistor (Q-55)	1	2N335	Texas Inst.
Transistor (Q-54)	1	2N329	Raytheon
Transistor (Q-51, Q-52, Q-53)	3	2N336	Texas Inst.
Crystal Diode (CR-60)	1	SV808	Transitron
Crystal Diode (CR-59)	1	SV5	Transitron
Potentiometer (R-108)	1	301-00 20K	Daystrom Pacific
Crystal Diode (CR-51, CR-52, CR-53, CR-54, CR-55, CR-56, CR-57, CR-58)	8	1N679	Transitron
Potentiometer (R-124)	1	301-00 200 Ohm	Daystrom Pacific
Resistor (R-137)	1	CB 1K 5% 1/4 watt	Allen Bradley
Resistor (R-136)	1	CB 1 Meg 5% 1/4 watt	Allen Bradley
Resistor (R-135)	1	EB 51 Ohm 5% 1/2 watt	Allen Bradley
Resistor (R-132, R-134)	2	RN 60B 59.0 K 1% 1/4 watt	Key Resistor Corp.
Resistor (R-131, R-133)	2	EB 4.7 Meg 5% 1/2 watt	Allen Bradley
Resistor (R-128, R-130)	2	771-1 150K 1%	Ohmite
Resistor (R-126, R-127)	2	771-1 7.5K 1%	Ohmite
Resistor (R-122, R-123)	2	GB 2.2K 5% 1 watt	Allen Bradley
Resistor (R-116)	1	GB 3.9K 5% 1 watt	Allen Bradley

6.2.1.2 g Compensation Circuit Board Assembly (Nortronics P/N 5212197):

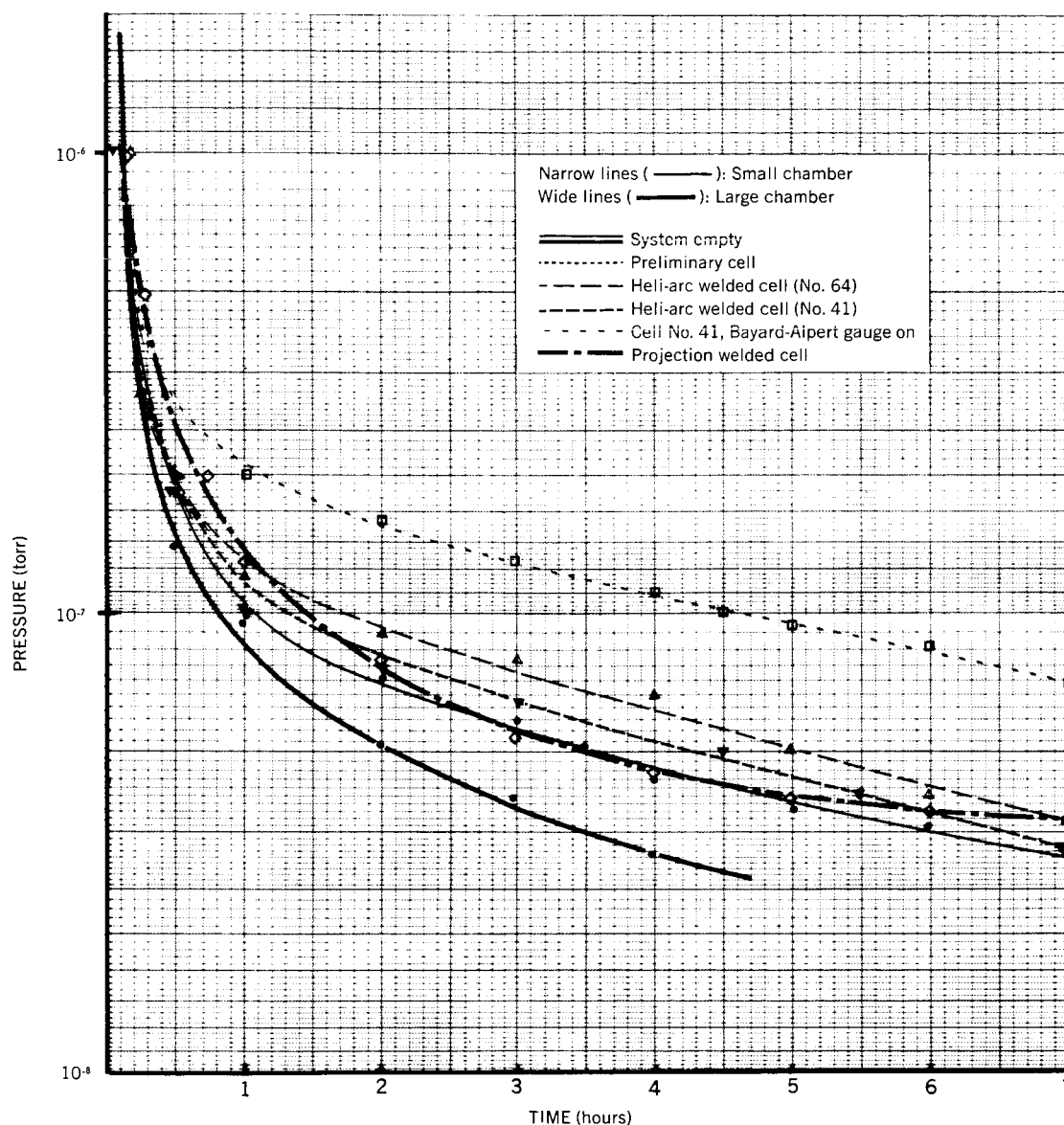
(cont'd)

<u>Part Nomenclature</u>	<u>Parts/Sensor</u>	<u>Vendor P/N</u>	<u>Vendor</u>
Resistor (R-115, R-117)	2	CB 100 ohm 5% 1/4 watt	Allen Bradley
Resistor (R-110)	1	CB 82K 5% 1/4 watt	Allen Bradley
Resistor (R-107, R-111, R-118)	3	CB 100K 5% 1/4 watt	Allen Bradley
Resistor (R-106, R-109)	3	RN 60B 49.9K 1% 1/4 watt	Key Resistor Corp.
Resistor (R-113, R-112, R-114, R-104)	4	CB 10K 5% 1/4 watt	Allen Bradley
Resistor (R-102)	1	RN 65 2 meg 1% 1/2 watt	Key Resistor Corp.
Resistor (R-101)	1	RN 70 9.76 meg 1% 1 watt	Key Resistor Corp.
Capacitor (C-59, C-60)	2	RQL2-IM IMFD, 200v	Astron
Capacitor (C-57, C-58)	2	29F905 Group 3 180 MFD, 30v	General Electric
Capacitor (C-55, C-56)	2	337Y474J .47 MFD, 150v	Gudeman
Capacitor (C-54)	1	29F910 Group 3 30 MFD 30v	General Electric
Capacitor (C-53)	1	150D475 x 003- 5B2 4 MFD 35v	Texas Inst. or Sprague
Capacitor (C-52)	1	CM15 22 MFD	Arco Elmenco

6.2.1.3 α and β Circuit Board Assembly (Nortronics P/N 4212175)Two Required per Sensor

<u>Part Nomenclature</u>	<u>Parts/Sensor</u>	<u>Vendor P/N</u>	<u>Vendor</u>
Resistor (R-58)	2	60B 581K 1% 1/4 watt	Key Resistor Corp.
Resistor (R-56)	2	HB 2.7K 5% 2 watt	Allen Bradley
Resistor (R-33)	2	GB 10K 1 watt	Allen Bradley
Resistor (R-12)	2	GB 3.9K 1 watt	Allen Bradley
Resistor (R-29)	2	EB 10 ohm 1/2 watt	Allen Bradley
Resistor (R-59)	2	CB 510K 1/4 watt	Allen Bradley
Resistor (R-46)	2	CB 2 M 1/4 watt	Allen Bradley
Resistor (R-32)	2	CB 1K 1/4 watt	Allen Bradley
Resistor (R-28)	2	CB 15K 1/4 watt	Allen Bradley
Resistor (R-30)	2	CB 2K 1/4 watt	Allen Bradley
Resistor (R-11, R-55)	4	CB 200 ohm 1/4 watt	Allen Bradley
Resistor (R-26, R-51, R-8)	6	CB 20K 1/4 watt	Allen Bradley
Resistor (R-54, R-52, R-31) R-27, R-9, R-7, R-60)	14	CB 10K 1/4 watt	Allen Bradley
Resistor (R-6, R-50)	4	CB 100K 1/4 watt	Allen Bradley
Resistor (R-5, R-49, R-25)	6	CB 82K 1/4 watt	Allen Bradley

FIG. 36. TEST CURVES OBTAINED BY PUMP-DOWN METHOD



E. OTHER EXPERIMENTAL FINDINGS

The difference between pressure readings obtained from the Bayard-Alpert gauge and by reading pump current drain was an object of some concern. When the Bayard-Alpert gauge had been recently outgassed, there was close agreement between the gauge and the pump. Within a few days following gauge outgassing, however, there was a great disparity between pump and gauge readings; this disagreement rose to a factor of 10:1 within several days. The conductance of the tube between the gauge and the test chamber is high enough (15 l./sec.) that the error introduced by the tube is less than 5%; correction was made for the conductance through the port between the test chamber and the ionization pump in these calculations. Since it is known that Bayard-Alpert performance characteristics do change with prolonged operation, it was assumed that the readings obtained from the pump were the more reliable.

It was interesting to note through the course of this work that outgassing from the cells themselves did not seem to be as severe a problem as we had anticipated, although outgassing effects from the ionization pump were an important factor, particularly when testing by the rate-of-rise method. As has been discussed previously, there was no discernible difference in the performance of test cells that had been purged with

nitric acid and then merely rinsed in acetone, as opposed to those which were cleansed in a carbonate-silicate solution which is believed throughout the industry to do a very thorough job of cleansing test articles of this nature. Furthermore, toward the latter days of the program, projection-welded cells became available and were tested. These cells have a deep crevice in the seal area, between the edge of the cover and the flange of the can. We had originally feared that this crevice might be difficult to clean, and that outgassing from it might be a grave problem. This, however, proved not to be the case.

During the course of the program, a few cells containing our present commercial nylon gasket seal were tested. The better of these cells had leak rates in the neighborhood of 10^{-5} atm. cc/sec., or lower. This is very close to the 10^{-6} atm. cc/sec. that many space agencies accept as being satisfactory for space use.

V. CONCLUSIONS — AREAS FOR FUTURE STUDY

A high vacuum method of testing cell seals has been developed which makes it possible to perform tests with a dynamic system, without requiring that the evacuated chamber be sealed off. The method is sensitive enough to detect leaks in the order of 10^{-8} atm. cc/sec. It is faster than other known methods of vacuum testing. Leaks of 5×10^{-7} atm. cc/sec. can be detected within 4 hours. Testing to a sensitivity of 5×10^{-8} atm. cc/sec. requires 10 to 12 hours; within 30 to 40 hours, a sensitivity of 2×10^{-8} atm. cc/sec. can be obtained. In applications where test sensitivity of 1×10^{-6} atm. cc/sec. is satisfactory, a complete test can be performed within 2 hours.

This method, which we have called the pump-down method, involves recording of system pressure by reading the current drawn by an ionization pump. The pressure of the system containing a test cell is recorded as the chamber is being pumped down. Comparing the slope of this pump-down curve, and the height of the base pressure that is obtained, with the standard curve of the empty system will reveal the extent of the leakage from the cell.

The time required per test could, of course, be reduced considerably by using a multiple-article test method. This would involve placing several cells (4, for example) in the test chamber. If a leak is detected, one of this lot of cells would be placed in the chamber together with the next group of three cells; if no leak is detected on this test, all 4 cells, including the one from the initial lot, are known to be good, and a second cell from the initial lot can be placed in the test chamber together with another group of 3. If, however, a leak is detected on the second test, one of the second group of three cells is separated from the lot and placed in the chamber with the third group of three. This process of separation and sequential testing can be continued indefinitely, and makes it possible to test a relatively large number of cells within a short period of time.

The elevated base pressure method of detecting leaks which was described in the program proposal has thus far proven unworkable, largely because of overheating of the cells in the test chamber. This method would have involved pumping the system down to its base pressure, then overcharging the cell and reading the resultant increase in system pressure. It was found, however, that the increase in cell internal pressure does not become significant before 2 or 3 hours following application of the overcharge current; even then, the increase in internal pressure is very gradual so that no sharp increase in system pressure is produced. By the time the increase in system pressure has become discernible, the cell has become severely overheated, is outgassing at an accelerated rate, and may even be damaged if these conditions are maintained for too long. This effect is puzzling, since the cell is laying on the walls of the steel test chamber, which should act as a heat sink. Overheating of cells in a vacuum should be thoroughly investigated, since this is critical in space applications. As the first step in exploring this effect further, cells might be securely fixed to the end plate so as to assure optimum contact between the cell case and the metal mass of the test system. Test performance in this setup would indicate whether it is worthwhile to pursue development of a heat sink design for cells of this type.

We feel that the time required per test with the pump-down method could be reduced considerably, and that this is one area that should be given serious future study. The pump presently used with the system has a capacity of 8 l./sec. The next larger pump size available in this particular line has a capacity of 40 l./sec. We have been advised by one vacuum authority that 8 l./sec. is somewhat less than optimum for a system having the size and operational requirements of our present design. With the pumping capacity of 40 l./sec., it is expected that the time required per test could be cut at least in half — perhaps more. With minimum design modification, the present system would accommodate a 40 liter pump. We feel, therefore, that the use of higher pumping capacity is one improvement in this test method that should be given serious consideration.

It was interesting to note that a few of our present commercial-grade "D" cells performed quite well in the test system, exhibiting leak rates in the neighborhood of 10^{-5} atm. cc/sec. These cells have a nylon-to-metal seal, formed by a nylon gasket which is crimped between the edge of the cover and the can rim. The surprisingly good performance of this cell seal leads us to feel that one promising area of future study would be investigation of compliant, resinous seal materials in new design configurations for space use.

6.2.1.3 α and β Circuit Board Assembly (Nortronics P/N 4212175)Two Required per Sensor (cont'd)

<u>Part Nomenclature</u>	<u>Parts/Sensor</u>	<u>Vendor P/N</u>	<u>Vendor</u>
Resistor (R-3, R-47)	4	CB 1M 1/4 watt	Allen Bradley
Resistor (R-10, R-53, R-2)	6	CB 510 ohm 5% 1/4 watt	Allen Bradley
Resistor (R-57)	2	RN 65 2M 1% 1/2 watt	Key Resistor Corp.
Resistor (R-40, R-41)	4	RN 60B 113K 1% 1/4 watt	Key Resistor Corp.
Resistor (R-39)	2	RN 60B 100 ohm 1% 1/4 watt	Key Resistor Corp.
Resistor (R-38)	2	RN 60B 30.1 K 1% 1/4 watt	Key Resistor Corp.
Resistor (R-37)	2	RN 60B 255 K 1% 1/4 watt	Key Resistor Corp.
Resistor (R-35)	2	RN 60B 232 K 1% 1/4 watt	Key Resistor Corp.
Resistor (R-34)	2	RN 60B 22.1 K 1% 1/4 watt	Key Resistor Corp.
Resistor (R-24)	2	RN 60B 100 K 1% 1/4 watt	Key Resistor Corp.
Resistor (R-23)	2	RN 60B 10K 1% 1/4 watt	Key Resistor Corp.
Resistor (R-20)	2	RN 60B 1 meg 1% 1/4 watt	Key Resistor Corp.
Crystal Diode (CR-13)	2	SV11	Transitron
Crystal Diode (CR-12, CR-1)	4	SV5	Transitron

6.2.1.3 α and β Circuit Board Assembly (Northronics P/N 4212175)Two Required per Sensor (cont'd)

<u>Part Nomenclature</u>	<u>Parts/Sensor</u>	<u>Vendor P/N</u>	<u>Vendor</u>
Crystal Diode (CR-7)	2	SV9	Transitron
Crystal Diode (CR-8, CR-9, CR-10, CR-3, CR-4, CR-5, CR-6, CR-11)	16	1N459	Transitron
Crystal Diode (CR-2)	2	SV808	Transitron
Resistor (R-18, R-19)	4	RN 60B 332 K 1% 1/4 watt	Key Resistor Corp.
Resistor (R-13)	2	RN 60B 499 K 1% 1/4 watt	Key Resistor Corp.
Resistor (R-1)	2	RN 60B 16.9 K 1% 1/4 watt	Key Resistor Corp.
Resistor (R-45, R-42, R-43, R-44, R-17, R-16, R-15, R-14)	16	PH 3.5 K 0.1%	Resistance Product Corp.
Potentiometer (R-4, R-48)	4	301 20K	Daystrom Pacific
Variable Capacitor (C-9)	2	VC 21G	J.F.D. Electronics
Capacitor (C-10)	2	TG .05 MFD 50V	Sprague
Capacitor (C-8)	2	96P2249154 .22 MFD 100V	Sprague
Capacitor (C-5)	2	4.7 MFD 35V	Texas Inst.
		150D475x0035B2	Sprague
Capacitor (C-3)	2	TAP 2 MFD 90V	Mallory
Capacitor (C-7, C-2)	4	CM 15 360 MMFD	Arco Elmenco
Capacitor (C-1, C-4)	4	96P3339154 .033 MFD 100V	Sprague

6.2.1.3 α and β Circuit Board Assembly (Nortronics P/N 4212175)Two Required per Sensor (cont'd)

<u>Part Nomenclature</u>	<u>Parts/Sensor</u>	<u>Vendor P/N</u>	<u>Vendor</u>
Potentiometer (R-21)	2	301 5K	Daystrom Pacific
Resistor (R-22)	2	CB 4.7K 1/4 watt	Allen Bradley
Thermistor ()	2	37A1	Victory Eng. Co.
Thermistor (Q-6)	2	2N 328	Raytheon
Transistor (Q-12, Q-4)	4	2N 343	Texas Inst.
Transistor (Q-11, Q-9, Q-8, Q-7, Q-3)	10	2N 335	Raytheon
Transistor (Q-10, Q-2)	4	2N 329	Raytheon
Transistor (Q-14, Q-13, Q-5, Q-1)	8	2N 336	General Electric
Transformer (T-2)	2	DOT-25	United Transformer Corp.
Transformer (T-1)	2	MMT-8	Microtan
Capacitor (C-6)	2	96P1049154 0.1 MFD 100V	Sprague

6.2.1.4 Fail Warning and Temperature Control Circuit Board Assembly
(Nortronics P/N 4213793):

<u>Part Nomenclature</u>	<u>Parts/Sensor</u>	<u>Vendor P/N</u>	<u>Vendor</u>
Relay ()	1	3S2791G200S-9	General Electric
Transistor (Q-60, Q-62)	2	2N336	Texas Inst.
Transistor (Q-59, Q-61)	2	2N 656	Transitron
Crystal Diode (CR-63, CR-66)	2	1N 2033	Transitron
Crystal Diode (CR-64, CR-67)	2	1N 459	Transitron
Crystal Diode (CR-62)	1	1N 747	Transitron

6.2.1.4 Fail Warning and Temperature Control Circuit Board Assembly

(Nortronics P/N 4213793): (cont'd)

<u>Part Nomenclature</u>	<u>Parts/Sensor</u>	<u>Vendor P/N</u>	<u>Vendor</u>
Crystal Diode (CR-61)	1	1N750	Transitron
Crystal Diode (CR-65)	1	1N1877A	Transitron
Resistor (R-149)	1	CB 180Ω 5% 1/4 watt	Allen Bradley
Resistor (R-145)	1	CB 390Ω 5% 1/4 watt	Allen Bradley
Resistor (R-141, R-148)	2	CB 1K 5% 1/4 watt	Allen Bradley
Resistor (R-142, R-146)	2	CB 2K 5% 1/4 watt	Allen Bradley
Resistor (R-143, R-147)	2	CB 3.9K 5% 1/4 watt	Allen Bradley
Resistor (R-140)	1	EB 5.6K 5% 1/2 watt	Allen Bradley
Resistor (R-144)	1	GB 680 5% 1 watt	Allen Bradley
Resistor (R-150)	1	GB 1.8K 5% 1 watt	Allen Bradley
Resistor (R-139, R-138)	2	GB 1.2K 5% 1 watt	Allen Bradley

6.2.2 Sphere Actuation Assembly (Nortronics P/N 5212143):

<u>Part Nomenclature</u>	<u>Parts/Sensor</u>	<u>Vendor P/N</u>	<u>Vendor</u>
Hydraulic Servo Valves	2	261350-1	Hydraulic Research and Mfg. Co.
Synchro Transmitters	2	SG-17-A-1	Clifton Precision Products Co.

6.2.2. Sphere Actuation Assembly (Nortronics P/N 5212143): (cont'd)

<u>Part Nomenclature</u>	<u>Parts/Sensor</u>	<u>Vendor P/N</u>	<u>Vendor</u>
Actuator Shaft Bearings	2	AMS7K	Fafnir Brg. Co.
β Yoke Bearing	1	A541	Fafnir Brg. Co.
β Synchro Shaft Bearing	1	AAS5W1DDFT DU	Fafnir Brg. Co.
Electrical Connector (P-9 plug, P-10 plug)	2	126-195	Amphenol
Electrical Connector (P-9 socket, P-10 socket)	2	126-196	Amphenol
Sphere Orifice Hose	4	3/16" 1.d., #1037 Silicone Comp.	Sonfarrel
Sphere Pitot Hose	1	1/2" 1.d., #1037 Silicone Comp.	Sonfarrel
Hydraulic Filter Cartridge	1	AC 1182E-2	Aircraft Porious Media
Actuator Piston Seals:	4	MS 29513-11, Comp. 363-70	Parco
O-rings	4	MS 29513-110, Comp. 363-70	Parco
Cap Strips	4	S11338-11, S11338-110,	W.S. Shamban Co. W.S. Shamban Co.
Actuator Cylinder Cap Seals:	4	MS 29513-13, Comp. 363-70	Parco
O-rings	4	S11248-13	W.S. Shamban Co.
Backup rings	4		

6.2.2 Sphere Actuation Assembly (Nortronics P/N 5212143): (cont'd)

<u>Part Nomenclature</u>	<u>Parts/Sensor</u>	<u>Vendor P/N</u>	<u>Vendor</u>
α Actuator Shaft Slip Ring Seals: O-rings	3	MS 29513-12, Comp. 363-70	Parco
Cap Strips	3	S11589-12	W.S. Shamban Co.
α Actuator Shaft to β Yoke Seals: O-rings	3	MS 29513-7, Comp. 363-70	Parco
α Actuator Cap Seals: O-ring	1	MS 29513-28, Comp. 363-70	Parco
O-ring	1	MS 29513-18, Comp. 363-70	Parco
Cap Strip	1	S11589-18	W.S. Shamban Co.
β Actuator Shaft Seals: O-ring	1	MS 29513-16, Comp. 363-70	Parco
Cap Strip	1	S11589-16	W.S. Shamban Co.
O-ring	1	MS 29513-12, Comp. 363-70	Parco
Cap Strip	1	S11589-12,	W.S. Shamban Co.
α Actuator to Hydraulic Manifold: O-rings	5	MS-29513-7, Comp. 363-70	Parco
Hydraulic Filter Hous- ing Seals: O-rings	1	MS-29513-16, Comp. 363-70	Parco
Backup ring	1	S11248-16	W.S. Shamban Co.
O-ring	1	MS-29513-113, Comp. 363-70	Parco

6.2.2 Sphere Actuation Assembly (Nortronics P/N 5212143): (cont'd)

<u>Part Nomenclature</u>	<u>Parts/Sensor</u>	<u>Vendor P/N</u>	<u>Vendor</u>
Aft Orifice Hose Fitting:			
O-rings	1	MS 29513-16, Comp. 363-70	Parco
O-rings	4	MS 29513-11, Comp. 363-70	Parco

6.2.3 Rear Bulkhead Assembly (Nortronics P/N 5212203):

<u>Part Nomenclature</u>	<u>Parts/Sensor</u>	<u>Vendor P/N</u>	<u>Vendor</u>
Hydraulic Coupling	1	240-58013	North American Aviation, Inc.
LN ₂ & Pitot Coupling	1	240-53457	North American Aviation, Inc.
Electrical Connector Guide	1	240-75151	North American Aviation, Inc.

6.2.4. Electrical Cable Assembly (Nortronics P/N 4213784):

<u>Part Nomenclature</u>	<u>Parts/Sensor</u>	<u>Vendor P/N</u>	<u>Vendor</u>
Electrical Connector (P-1 socket)	1	PT 07P-14-19S	Bendix
Electrical Connector (P-2 socket)	1	PT 07P-14-19SW	Bendix
Electrical Connector (P-3 plug)	1	CA-19618-17	Cannon Electric
Electrical Connector (P-4 socket)	1	PT-07P-18-32S	Bendix
Electrical Connector (P-5 socket)	1	DB 15S	Cannon Electric
Electrical Connector (P-6 socket)	1	DB 15S	Cannon Electric

6.2.5 Thermistor Probe Assembly (Nortronics P/N 4213920 & P/N 4214959):One Each Required Per Sensor

<u>Part Nomenclature</u>	<u>Parts/Sensor</u>	<u>Vendor P/N</u>	<u>Vendor</u>
Thermistor	2	31D10	Victory Eng. Co.

6.2.6 Flow-Direction Sensor Assembly (Nortronics P/N 4212138):

<u>Part Nomenclature</u>	<u>Parts/Sensor</u>	<u>Vendor P/N</u>	<u>Vendor</u>
Cone Insulation	2	5212188 (Nortronics P/N)	H.I. Thompson Co.
Electrical Connector (P-7 plug)	1	DCH-37P-002-F9	Cannon Electric
Electrical Connector (P-8, P-11 Sockets)	2	DA-15S	Cannon Electric
Electrical Connector (P-5, P-6, P-8, P-11 Plugs)	4	DA-15P	Cannon Electric
LN ₂ Valve Fitting Seals: O-rings	4	AN 6290-4 Comp. 363-70	Parco
LN ₂ Filter Seals: O-rings	1	AN 6290-4 Comp. 363-70	Parco
Blowdown Switch	1	M1-015-15-252	Metals and Controls Div. of Texas Inst. Inc.